Land Disposal of Sewage Sludge

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esearch Program for the Abatement of Municipal Pollution
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VOLUME V

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by

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ABSTRACT

The objective of this research was to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface water with nitrate nitrogen, and surface waters with elements pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

This volume covers the period from April 1, 1976, to March 31, 1977 and discusses the results from the fourth year of field runoff studies with fall, winter and spring applied fluid sewage sludge on land cropped with grain corn. Nutrients and metals in runoff water were measured. The report also covers the fourth year of field rate and source studies with three sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride and aluminum sulphate for phosphorus removal. One experiment involved surface sludge applications on a loam soil on which bromegrass was grown, and two experiments involved corn on a loam, and a sandy soil. In a greenhouse experiment six fluid sewage sludges, selected for their high metal content, were applied to a soil previously adjusted to two pH levels. Eight crops of ryegrass were grown with sludges added before each crop. Half of the treatments received no sludge after the fifth crop. Crop growth and nutrient and metal uptake were studied. Field and laboratory studies have been used to estimate the nitrogen available from sludges and the rates of volatilization of nitrogen from surface applied sludge in the field.

Runoff losses continued to be small, with generally less than 1 kg N or 0.5 kg P/ha lost in one year. Rainfall and winter frost conditions appear to be more important than total precipitation in determining runoff losses. Sludge application in winter does not create added hazards provided reasonable precautions are taken.

In the field rate and source studies the bromegrass yielded slightly more with sludge than with ammonium nitrate. Corn yields were little affected by nitrogen or sludge in 1975 or 1976.

The sludges increased sodium bicarbonate-extractable (plant available) soil phosphorus markedly, with the calcium sludge being much more effective than the other sludges. Phosphorus concentrations in the crops were high, and little affected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application - greatest with the aluminum and iron sludges. Chromium was increased in some plant tissues at some sites, but results were inconsistent. Copper, nickel and zinc concentrations in bromegrass and corn stover increased with high rates of sludge application.

In the greenhouse study increased rates of sludge applied at one time increased the concentrations of metals in ryegrass, with the exception of mercury and selenium. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next at any of the rates studied. One exception to this was zinc, which showed some increase from the fifth to the eighth crop.

In a study of the extraction of metals from soils, it appeared that aqua regia extraction may be satisfactory as a measure of total metals added to soils in sewage sludges.

In the nitrogen field studies it was found that nitrate-N concentration in early April was higher where sludge was applied in previous years on the corn experiments, suggesting that residual sludge N was being mineralized and nitrified. The nitrate-N concentration in the soil was usually lower under grass than under corn.

Nitrogen studies on abandoned runoff plots showed increased nitrate-N concentrations in the soil on April 8 where sludge had been applied in the previous fall or winter over that present where sludge had been applied in the previous springs, but not in 1976.

RESUME

Le but de la présente recherche était de déterminer les doses maximales de boues pouvant être appliquées sur un sol cultivé sans entraîner la contamination des eaux souterraines par l'azote nitrique, ni celle des eaux de surface par des éléments pathogènes pour l'homme et les animaux et sans diminuer le rendement ou la qualité de la récolte.

Le rapport porte sur la période du 1er avril 1976 au 31 mars 1977, et rend compte des résultats obtenus lors de la quatrième année d'étude du ruissellement suivant l'épandage des boues liquides en automne, en hiver et au printemps sur des sols cultivés en maïs. On a mesuré la teneur en matières nutritives et en métaux des eaux de ruissellement. Il est aussi question de la quatrième année d'études des doses d'épandage et de l'origine de trois types de boues provenant de la déphosphatation des eaux usées avec de l'hydroxyde de calcium, du chlorure ferrique et du sulfate d'aluminium. Dans une des expériences, on a épandu les boues sur des terres grasses cultivées en brome et, dans deux autres, on a étudié des terres grasses et des terres sablonneuses cultivées en maïs. Dans une expérience en serres, six types de boues liquides, choisies pour leur haute teneur en métaux, ont été épandues sur un sol préalablement ajusté à deux pH différents. On a effectué huite récoltes de faux seigle en épandant des boues entre chaque période de culture. Dans la moitié des groupes, on a interrompu l'épandage après la cinquième récolte. On a étudé la croissance végétale et l'absorption des matières nutritives et des métaux. Des expériences sur le terrain et en laboratoire ont permis d'évaluer la quantité d'azote assimilable des boues et sa vitesse de volatilisation lorsque l'application se fait à la surface du sol.

Les pertes dues au ruissellement ont continué d'être faibles, s'élevant généralement à moins de 1 kg de N ou à 0,5 kg de P par hectare, en un an. Ces pertes semblent dépendre plus des averses et des conditions de gel hivernales que des précipitations totales. L'épandage de boues en hiver ne crée pas de dangers supplémentaires lorsque des précautions suffisantes sont prises.

Les études des doses épandues et de la provenance des boues ont démontré que le rendement des cultures de brome était légèrement plus

élevé qu'avec le nitrate d'ammonium. L'azote ou les boues épandues en 1975 et en 1976 n'ont eu que peu d'effet sur les rendements des cultures de maïs.

Les boues ont accru de façon marquée la proportion de phosphore du sol assimilable par les plantes et extractible par le bicarbonate de soude. Les boues de calcium se sont montrées beaucoup plus efficaces sous cet aspect. Dans les plantes récoltées, les concentrations de phosphore étaient élevées et peu modifiées par le traitement.

Les épandages de boues ont augmenté la teneur en cadmium tant de l'herbe que des tiges de maïs; les boues d'aluminium et de fer ont été les plus efficaces sous cet aspect. La teneur en chrome a augmenté dans certains tissus végétaux et à certains endroits, mais non de façon soutenue. Les teneurs en cuivre, en nickel et en zinc se sont accrues dans le brome et dans les tiges de maïs avec les doses élevées d'épandage de boues.

En serres, l'augmentation de la dose épandue en une fois a augmenté la teneur en métaux du faux seigle, à l'exception du mercure et du sélénium. Après des applications et des récoltes répétées, cette teneur n'a pas augmenté d'une récolte à l'autre et ce, quelle que fût la dose utilisée. La seule exception au tableau était le zinc, pour lequel on a noté une légère augmentation entre la cinquième et la huitième récolte.

Une étude de l'extraction des métaux du sol a démontré que l'extraction à l'eau régale était propice pour mesurer la quantité totale de métaux ajoutée par l'épandage des boues.

Les études sur le terrain portant sur l'azote ont démontré que la teneur en azote nitrique, mesurée au début d'avril, est plus élevée lorsque les boues ont été épandues l'année précédente sur les sols cultivés en maïs; ce qui porte à croire que l'azote résiduel des boues a été minéralisé et nitrifié. La teneur en azote nitrique était habituellement moins élevée dans les sols cultivés en herbes que dans ceux qui étaient cultivés en maïs.

Des études de l'azote dans des parcelles de ruissellement abandonnées ont démontré une augmentation des teneurs en azote nitrique, le 8 avril, aux endroits où des boues avaient été épandues l'automne ou l'hiver précédent, par rapport aux teneurs enregistrées là où des boues avaient été épandues le printemps précédent mais non en 1976.

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1. INTRODUCTION

This volume covers the results of investigations carried out by the Department of Land Resource Science at the University of Guelph on land disposal of sewage sludge. The work was financed by Fisheries and Environment Canada and the Ontario Ministry of the Environment under project 72-5-17, contracted by the Federal Department of Supply and Services, and covers the period from April 1, 1976 to March 31, 1977. Previous work under this project has been published as Land Disposal of Sewage Sludge, Research Reports No. 16, 24, 35 and 60, Volumes I, II, III and IV, respectively, under provisions of the Canada-Ontario Agreement on Great Lakes Water Quality.

The research program proceeded on schedule during 1975/76. April was warmer than normal allowing an early start at sludge application in the field. This advantage was compensated for by a wet period in early May with the result that seeding dates were about normal. The summer had few periods of above average temperature, but the heat unit accumulation was similar to the long-term average and moisture was well-distributed. The corn crops suffered little from drought even on the loamy sand soil at Cambridge. The bromegrass probably suffered from moisture deficiency in the second and third cut.

The microbial studies were not continued in 1976 as they appeared to have reached their objectives. Other facets of the project were reduced or eliminated where they did not appear to warrant further effort with the limited funds available. The runoff plots on 2% slopes were dropped from the runoff study in 1976, leaving only the plots on 6% slopes. The plots on 2% slopes were used to obtain information on the residual value of nitrogen from sludge applied in previous years. Chemical analyses of the second and third cut of bromegrass were discontinued as they make up a small proportion of the total season's yield.

As the work continues it becomes increasingly interesting to study the changes or lack of them in metal and nutrient uptake from year to year and crop to crop. The patterns emerging are not what was expected.

2. OBJECTIVES

The objective of this research is to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface water with nitrate nitrogen, and surface waters with elements pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

3 RUNOFF

3.1 Objectives

This section of the sludge project was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year.

3.2 Experimental

3.2.1 Design

Runoff was measured at the Elora Research Station on an imperfect to poorly drained sandy clay loam soil with systematic tile drains. Field plots, 0.025 ac (0.01 hectare) on 2% and 6% slopes with suitable edging and runoff collection devices, were installed in the fall of 1972. Fluid iron precipitated sludge from the North Toronto sewage treatment plant was applied to separate plots each November, January and April.

Rates of application based on the nitrogen content of the sludge were 178 lb N/ac (200 kg N/ha) and 712 lb N/ac (800 kg N/ha) on the 2% slope and 178 lb N/ac (200 kg N/ha) on the 6% slope. On each slope the treatment without sludge received 100 lb N/ac (112 kg N/ha) as NH_4NO_3 in the spring. There were two replicates of each treatment.

After each runoff event the volumes of water collected were measured, sampled taken and tanks emptied. In the winter period (January April 1976) runoff was collected from both 6% and 2% slopes. Commencing with the spring treatment April 13, 1976, sludge was applied to the 6% plots only since it had been decided to discontinue the 2% plots. The runoff area was plowed (May 19), and planted (May 20).

3.2.2 Water analysis

Soluble nitrogen and phosphorus in the water samples were determined directly using an automated procedure after passing through a 0.45 μ filter. Total nitrogen and phosphorus in the unfiltered water sampled were determined using an automated procedure after digestion with H_2SO_4-H_2O_2 (Thomas et al., 1967).

Soluble metals (Cd, Cu, Ni, Pb and Zn) were determined by atomic absorption using a Varian-Techtron AA6 with a CRA 90 furnace after the water samples were passed through a 0.45 μ filter. Acid extractable metals were determined by digesting unfiltered water samples with aqua regia; the concentrations were determined using standard atomic absorption techniques.

Mercury content of filtered (0.45 μ) water samples was determined by flameless atomic absorption (Hamm and Stewart, 1973) after oxidation of the organic materials with potassium permanganate and potassium persulphate. Sediment collected on the filters was digested with aqua regia at 60°C before mercury determination by flameless atomic absorption.

3.3 Results and Discussion

3.3.1 Crop yield

Germination was normal and the stand thinned to 20,000 plants per acre on June 17. The corn was harvested on October 15, and the yields are given in Table 1. There was little difference in yield between different times of application. Yields for all treatments were considerably lower than the yields for 1975, but were higher than 1974 or 1973.

3.3.2 Precipitation and runoff losses

Total precipitation for the three runoff periods ending January 20, 1977 (Tables 2, 3 and 4) was 97.10 cm. This is 11% higher than in the previous 12-month period ending December 31, 1975, and 11% more than the 30-year average for this region (Table 5). Only one runoff event occurred following the winter application of sludge (January 20), (Table 2), and one event occurred following the spring application of sludge (Table 3). Throughout the winter period the temperature of the soil was monitored at two depths (2 cm and 45 cm from the surface). The surface temperature ranged from 0°C to 1°C, while at 45 cm it ranged from 1°C to 3°C. Since the soil was never completely frozen, and with only three days in January above the freezing mark, it possibly explains why the number of runoff events was very low (one) as compared to the winter of 1975 (twelve).

The losses of total and soluble nitrogen and phosphorus are shown in Tables 6 and 7 for the winter period, and for the summer period in Table 8. The fall period in 1976 gave no runoff. Losses were lower than in 1975 in keeping with the reduced number of runoff events.

The soluble and the acid extractable metals (winter and summer periods) are shown in Tables 9, 10 and 11. Like the total and soluble nitrogen and phosphorus, the amounts of metals are considerably lower than in 1975 and 1974, because of the fewer number of events.

An estimate of the amount of organic material present in runoff water (winter and summer periods) is given by the value of the chemical oxygen demand (Table 12). Organic matter losses are also lower than previous years.

3.4 Conclusions

Runoff losses continued to be small, with generally less than one kilogram N or one-half kilogram P per hectare lost in one year.

Rainfall and winter frost conditions appear more important than total precipitation in determining runoff losses.

Sludge application in winter does not create added hazards provided reasonable precautions are taken, such as using the more level land, avoiding ice on the soil surface, and adhering to low application rates (200 kg N/ha or less).

TABLE 1. Yield of Corn (Shelled Grain*) in 1973, 1974, 1975 and 1976

Slope and Treatment		1973	1974	1975	1976
		lb/ac (kg/ha)			
6% slope					
200 kg N	Fall	4390 (4920)	4600 (5150)	7210 (8070)	5790 (6490)
	Winter	4010 (4490)	4450 (4990)	6690 (7490)	5320 (5970)
	Spring	4200 (4700)	4510 (5050)	6740 (7540)	5500 (6180)
	Check	4190 (4690)	4640 (5200)	6800 (7620)	6070 (6810)
2% slope					
200 kg N	Fall	4480 (5020)	6280 (7040)	8040 (9000)	
	Winter	3610 (4040)	6090 (6820)	7860 (8800)	
	Spring	4390 (4920)	5250 (5880)	8090 (9060)	
800 kg N	Fall	6030 (6750)	5070 (5670)	7860 (8800)	
	Winter	5760 (6450)	4810 (5390)	7970 (8930)	
	Spring	5690 (6370)	5580 (6250)	8090 (9060)	
	Check	4270 (4780)	4900 (5490)	7620 (8530)	

*15% moisture

TABLE 2. Rainfall in Winter Period, Elora. January 20 to April 12, 1976

Day of Month	Jan.		Feb.		Mar.		Apr.	
	in	cm	in	cm	in	cm	in	cm
1			0.09	0.23	1.5	3.68	0.06	0.15
2			0.01	0.03	0.70	1.78		
3			0.02	0.05	0.14	0.36		
4			0.02	0.05	0.46	1.17		
5			0.01	0.03	0.15	0.38		
6			0.02	0.05	0.05	0.13		
7			0.16	0.41	0.01	0.03		
8								
9								
10					0.23	0.58	0.06	0.15
11			0.05	0.13				
12					0.86	2.18		
13					0.02	0.05		
14					0.06	0.15		
15			0.26	0.66				
16			0.13	0.33	0.02	0.05		
17			0.21	0.53	0.01	0.03		
18			0.14	0.36	0.13	0.33		
19			0.01	0.03				
20	$\boxed{0.04}$	$\boxed{0.10}$	0.17	0.43	0.09	0.23		
21	0.05	0.13	0.42	1.07	0.04	0.10		
22					———	———		
23	0.13	0.33						
24	0.03	0.08			0.22	0.56		
25	0.62	1.57						
26	0.60	1.52	0.02	0.05				
27					0.27	0.67		
28	0.13	0.33	0.08	0.20				
29	0.01	0.03			T	T		
30					0.08	0.20		
31					0.55	1.40		
Monthly Total	1.61	4.09	1.82	4.62	5.54	14.07	0.12	0.30
Cumulative Total	1.61	4.07	3.43	8.71	8.97	22.78	9.09	23.08

☐ Denotes a date of sludge application.
——— Denotes a date on which a runoff occurred.
T Denotes trace (<0.01 in)

TABLE 3. Rainfall in Summer Period, Elora. April 13 to November 21, 1976

Day of Month	Apr. in	Apr. cm	May in	May cm	June in	June cm	July in	July cm
1			0.02	0.05			0.12	0.30
2			0.20	0.50			T	T
3			0.02	0.05			0.11	0.28
4								
5			0.31	0.79				
6			1.22	3.10				
7			0.01	0.03			0.56	1.42
8			T	T				
9							0.38	0.97
10			0.12	0.30			0.05	0.13
11			0.08	0.20				
12								
13	☐	☐	0.01	0.03	0.08	0.20		
14	0.59	1.50	0.05	0.13			0.01	0.03
15	0.64	1.63	0.08	0.20	0.09	0.23	0.22	0.56
16			0.20	0.50	0.04	0.10		
17			T	T				
18					0.12	0.30		
19					0.21	0.53		
20							0.71	1.80
21	0.19	0.48						
22	0.26	0.66						
23	0.03	0.08					0.03	0.08
24	1.30	3.30			0.49	1.24		
25	0.59	1.50	0.01	0.03				
26			T	T	0.25	0.63	0.02	0.05
27								
28					0.41	1.04	0.83	2.11
29					0.76	1.93	T	T
30	0.09	0.23	0.33	0.84	$\underline{1.21}$	$\underline{3.07}$	0.27	0.69
31			0.28	0.71			0.08	0.20
Monthly Total	3.69	9.37	2.94	7.47	3.66	9.30	3.39	8.61
Cumulative Total			6.63	16.84	10.29	26.14	13.68	34.75

☐ Denotes a date of sludge application.
— Denotes a date on which a runoff occurred.
T Denotes trace (<0.01 in).

TABLE 3. (Continued)

Day of Month	Aug.		Sept.		Oct.		Nov.	
	in	cm	in	cm	in	cm	in	cm
1			0.03	0.08			T	T
2							0.01	0.03
3			0.12	0.30			T	T
4							0.11	0.28
5	0.04	0.10					0.01	0.03
6					0.97	2.46		
7	0.18	0.46			T	T	0.02	0.05
8	0.49	1.24			T	T	0.01	0.03
9			0.57	1.45	0.15	0.38	0.11	0.28
10	T	T	0.25	0.63			0.03	0.08
11	T	T						
12	0.24	0.61						
13	0.35	0.89			0.25	0.63		
14	0.42	1.07						
15			T	T	0.05	0.13		
16			0.01	0.03				
17			2.49	6.32				
18								
19			0.40	1.02	0.43	1.09		
20			0.02	0.05	0.33	0.84	0.04	0.10
21			0.17	0.43	0.26	0.66	T	T
22			0.36	0.91	0.18	0.46		
23			0.01	0.03	0.12	0.30		
24					0.12	0.30		
25			0.01	0.03	0.01	0.03		
26	0.06	0.15	0.32	0.81	T	T		
27								
28								
29								
30					0.21	0.53		
31	0.46	1.17			T	T		
Monthly Total	2.24	5.69	4.76	12.09	3.08	7.82	0.34	0.86
Cumulative Total	15.92	41.44	20.68	52.53	23.76	60.35	24.10	61.21

☐ Denotes a date of sludge application.
— Denotes a date on which a runoff occurred.
T Denotes trace (<0.01 in).

TABLE 4. Rainfall in Fall Period, Elora. November 22, 1976 to January 20, 1977

Day of Month	Nov.		Dec.		Jan.	
	in	cm	in	cm	in	cm
1			0.12	0.30	0.01	0.03
2			0.02	0.05	0.02	0.05
3			0.13	0.33	0.06	0.15
4			0.03	0.08		
5			0.01	0.03		
6			0.19	0.48	0.08	0.20
7					0.02	0.05
8			0.02	0.05	0.05	0.38
9			0.01	0.03	0.31	0.79
10					0.08	0.20
11					0.03	0.08
12			0.05	0.38	0.01	0.03
13					0.18	0.46
14					0.04	0.10
15						
16			0.06	0.15	0.03	0.08
17			0.01	0.03	0.04	0.10
18					0.01	0.03
19			0.27	0.69		
20					0.01	0.03
21			0.02	0.05		
22	0.05	0.13	0.04	0.10		
23	0.01	0.03	0.04	0.10		
24	0.03	0.08				
25	0.19	0.48	0.03	0.08		
26	0.44	1.12	0.02	0.05		
27	0.01	0.03	0.10	0.25		
28	T	T	0.05	0.38		
29	0.02	0.05				
30	0.03	0.08				
31			0.03	0.08		
Monthly Total	0.78	1.98	1.25	3.18	0.98	2.49
Cumulative Total	0.78	1.98	2.03	5.16	3.01	7.65

☐	Denotes a date of sludge application.
—	Denotes a date on which a runoff occurred.
T	Denotes trace (<0.01 in)

TABLE 5. Monthly and Cumulative Precipitation for the Elora Research Station, 1976.

	January 1976-December 1976				30-year average			
Month	Monthly total		Cumulative total		Monthly total		Cumulative total	
	in	(cm)	in	(cm)	in	(cm)	in	(cm)
January	3.60	9.16	3.60	9.16	2.79	7.08	2.79	7.08
February	1.82	4.62	5.42	13.78	2.24	5.69	5.03	12.77
March	5.54	14.07	10.96	27.85	2.48	6.30	7.51	19.07
April	3.81	9.67	14.77	37.52	2.70	6.86	10.21	25.93
May	2.94	7.47	17.71	44.99	3.10	7.87	13.31	33.80
June	3.66	9.30	21.37	54.29	3.00	7.62	16.31	41.42
July	3.39	8.61	24.76	62.90	3.10	7.87	19.41	49.29
August	2.24	5.69	27.00	68.59	3.10	7.87	22.51	57.16
September	4.76	12.09	31.76	80.68	3.00	7.62	25.51	64.78
October	3.08	7.82	34.84	88.50	2.79	7.08	28.30	71.85
November	1.12	2.84	35.96	91.34	2.70	6.86	31.00	78.72
December	1.25	3.18	37.21	94.52	2.79	7.08	33.79	85.80

TABLE 6. Runoff Losses in Winter Period, January 20 to April 12, 1976. Total Nitrogen and Phosphorus

Slope and Treatment		Runoff*		Total Fraction Nitrogen		Total Fraction Phosphorus	
		in	(cm)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
6% Slope							
200 kgN	Fall	0.84	(2.13)	0.23	(0.26)	0.10	(0.11)
	Winter	0.84	(2.13)	0.41	(0.46)	0.04	(0.04)
	Spring	0.84	(2.13)	0.19	(0.22)	0.04	(0.04)
	Check	0.84	(2.13)	0.16	(0.17)	0.04	(0.04)
2% Slope							
200 kgN	Fall	0.62	(1.57)	0.13	(0.14)	0.04	(0.05)
	Winter	0.62	(1.57)	0.16	(0.18)	0.04	(0.05)
	Spring	0.62	(1.57)	0.11	(0.12)	0.03	(0.03)
800 kgN	Fall	0.62	(1.57)	0.16	(0.18)	0.05	(0.06)
	Winter	0.62	(1.57)	0.15	(0.17)	0.04	(0.04)
	Spring	0.62	(1.57)	0.13	(0.14)	0.03	(0.03)
	Check	0.62	(1.57)	0.15	(0.17)	0.03	(0.03)

* One runoff event - all tanks completely filled with a small amount of overflow.

TABLE 7. Runoff Losses in Winter Period, January 20 to April 12, 1976. Soluble Nitrogen and Phosphorus

				Soluble Fraction			
Slope and Treatment		Runoff*		Nitrogen		Phosphorus	
		in	(cm)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
6% Slope							
200 kgN	Fall	0.84	(2.13)	0.09	(0.10)	0.05	(0.05)
	Winter	0.84	(2.13)	0.04	(0.04)	<0.01	(<0.01)
	Spring	0.84	(2.13)	0.04	(0.04)	<0.01	(<0.01)
	Check	0.84	(2.13)	0.04	(0.04)	<0.01	(<0.01)
2% Slope							
200 kgN	Fall	0.62	(1.57)	0.04	(0.05)	0.03	(0.03)
	Winter	0.62	(1.57)	0.06	(0.06)	0.02	(0.02)
	Spring	0.62	(1.57)	0.03	(0.03)	0.01	(0.01)
800 kgN	Fall	0.62	(1.57)	0.06	(0.07)	0.03	(0.03)
	Winter	0.62	(1.57)	0.05	(0.06)	0.02	(0.02)
	Spring	0.62	(1.57)	0.03	(0.03)	0.01	(0.01)
	Check	0.62	(1.57)	0.04	(0.04)	0.01	(0.01)

* One runoff event - all tanks completely filled with a small amount of overflow.

TABLE 8. Runoff Losses* in Summer Period, April 13 to September 30, 1976. Total and Soluble Nitrogen and Phosphorus from 6 Percent Slope Plots.

Treatment		Runoff		Nitrogen		Phosphorus	
		in	(cm)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
				Total Fraction			
200 kg N	Fall	0.44	(1.12)	0.30	(0.33)	0.14	(0.16)
	Winter	0.27	(0.69)	0.19	(0.22)	0.08	(0.09)
	Spring	0.20	(0.51)	0.18	(0.20)	0.08	(0.09)
	Check	0.38	(0.97)	0.43	(0.49)	0.16	(0.18)
				Soluble Fraction			
200 kg N	Fall	0.44	(1.12)	0.02	(0.02)	0.02	(0.03)
	Winter	0.27	(0.69)	0.01	(0.01)	0.02	(0.02)
	Spring	0.20	(0.51)	0.01	(0.01)	0.01	(0.01)
	Check	0.38	(0.97)	0.04	(0.04)	0.02	(0.02)

* one runoff event (June 30)

TABLE 9. Acid-Extractable Metals in Runoff. Winter, 1976.

Slope and Treatment		Cd	Cu	Hg*	Ni	Pb	Zn
		lb/ac x 10^{-3} (kg/ha x 10^{-3})					
6% slope							
200 kg N	Fall	<0.02(<0.02)	3.67(4.11)	0.30(0.34)	2.6(2.9)	17.4(19.5)	18.4(20.6)
	Winter	<0.02(<0.02)	4.47(5.01)	0.13(0.15)	2.3(2.6)	44.5(49.8)	16.9(18.9)
	Spring	<0.02(<0.02	3.89(4.36)	0.09(0.10)	1.9(2.1)	69.6(78.0)	11.6(13.0)
	Check	<0.02(<0.02)	3.49(3.91)	0.12(0.13)	1.9(2.1)	30.9(34.6)	5.96(6.68)
2% slope							
200 kg N	Fall	<0.02(<0.02)	3.14(3.52)	0.16(0.18)	1.9(2.1)	0.7 (0.8)	5.37(6.01)
	Winter	<0.02(<0.02)	5.42(6.07)	0.18(0.20)	1.8(2.0)	<0.25(<0.25)	11.6(13.0)
	Spring	<0.02(<0.02)	3.84(4.30)	0.28(0.32)	2.3(2.6)	<0.25(<0.25)	8.77(9.82)
800 kg N	Fall	<0.02(<0.02)	4.76(5.33)	0.21(0.24)	1.4(1.6)	<0.25(<0.25)	12.1(13.5)
	Winter	<0.02(<0.02)	2.62(2.93)	0.17(0.19)	1.6(1.8)	<0.25(<0.25)	6.04(6.76)
	Spring	<0.02(<0.02)	4.01(4.49)	0.15(0.17)	2.1(2.4)	<0.25(<0.25)	11.8(13.2)
	Check	<0.02(<0.02)	2.36(2.64)	0.18(0.20)	1.8(2.0)	<0.25(<0.25)	5.36(6.00)

*Sum of Hg in filtered (0.45μ) water samples and in sediments.

TABLE 10. Soluble Metals in Runoff. Winter, 1976.

Slope and Treatment		Cd	Cu	Hg	Ni	Pb	Zn
				lb/ac x 10^{-3} (kg/ha x 10^{-3})			
6% slope							
200 kg N	Fall	<0.02(<0.02)	2.42(2.71)	0.24(0.27)	1.9(2.1)	<0.25(<0.25)	3.87(4.33)
	Winter	<0.02(<0.02)	3.67(4.11)	0.11(0.12)	1.9(2.1)	<0.25(<0.25)	13.0(14.5)
	Spring	<0.02(<0.02)	3.09(3.46)	0.06(0.07)	1.2(1.3)	<0.25(<0.25)	9.67(10.8)
	Check	<0.02(<0.02)	3.09(3.46)	0.10(0.11)	1.7(1.9)	<0.25(<0.25)	4.06(4.55)
2% slope							
200 kg N	Fall	<0.02(<0.02)	2.34(2.62)	0.09(0.10)	1.7(1.9)	<0.25(<0.25)	3.97(4.45)
	Winter	<0.02(<0.02)	2.62(2.93)	0.10(0.11)	1.3(1.5)	<0.25(<0.25)	4.53(5.07)
	Spring	<0.02(<0.02)	1.84(2.06)	0.22(0.24)	2.1(2.4)	<0.25(<0.25)	5.52(6.18)
800 kg N	Fall	<0.02(<0.02)	2.41(2.70)	0.14(0.16)	1.1(1.2)	<0.25(<0.25)	5.73(6.42)
	Winter	<0.02(<0.02)	1.92(2.15)	0.11(0.12)	1.4(1.6)	<0.25(<0.25)	3.54(3.96)
	Spring	<0.02(<0.02)	1.91(2.14)	0.11(0.12)	1.8(2.0)	<0.25(<0.25)	6.80(7.62)
	Check	<0.02(<0.02)	1.56(1.75)	0.15(0.16)	1.4(1.6)	<0.25(<0.25)	3.96(4.44)

TABLE 11. Soluble and Acid-Extractable Metals in Runoff. Summer, 1976.

Slope and Treatment		Cd	Cu	Hg	Ni	Pb	Zn
		lb/ac x 10^{-3} (kg/ha x 10^{-3})					
		Soluble fraction					
6% slope							
200 kg N	Fall	<0.02(<0.02)	2.38(2.67)	0.06(0.07)	1.0(1.1)	82.2(92.1)	7.45(8.34)
	Winter	<0.02(<0.02)	0.92(1.03)	0.04(0.04)	0.6(0.7)	17.4(19.5)	3.39(3.80)
	Spring	<0.02(<0.02)	1.43(1.60)	0.03(0.03)	0.6(0.7)	22.4(25.1)	4.73(5.30)
	Check	<0.02(<0.02)	0.89(1.00)	0.04(0.04)	0.4(0.4)	19.9(22.3)	7.79(8.72)
6% slope		Acid-extractable fraction					
200 kg N	Fall	<0.02(<0.02)	3.98(4.46)	0.08(0.09)*	1.7(1.9)	88.1(98.7)	15.6(17.5)
	Winter	<0.02(<0.02)	2.52(2.82)	0.05(0.06)	1.2(1.3)	31.0(34.7)	9.94(11.1)
	Spring	<0.02(<0.02)	1.63(1.83)	0.04(0.04)	0.9(1.0)	32.4(36.3)	9.73(10.9)
	Check	<0.02(<0.02)	2.94(3.29)	0.05(0.06)	2.0(2.2)	36.0(40.3)	18.4(20.7)

*Sum of Hg in filtered (0.45μ) water samples and in sediments.

TABLE 12. COD* in Runoff Water for Winter and Summer Periods, 1976.

Slope and Treatment		Winter		Summer	
		lb/ac	(kg/ha)	lb/ac	(kg/ha)
6% slope					
200 kg N	Fall	6.0	(6.7)	6.4	(7.2)
	Winter	4.5	(5.0)	3.7	(4.2)
	Spring	8.9	(10.0)	3.2	(3.6)
	Check	1.5	(1.7)	7.4	(8.3)
2% slope					
200 kg N	Fall	3.6	(4.0)		
	Winter	3.8	(4.3)		
	Spring	1.6	(1.8)		
800 kg N	Fall	4.9	(5.5)		
	Winter	7.0	(7.9)		
	Spring	3.4	(3.8)		
	Check	7.1	(8.0)		

* chemical oxygen demand

4. FIELD RATE AND SOURCE EXPERIMENTS

4.1 Objectives

The objective of the field rate and source experiments is to determine the rate of three chemically treated sludges which may be safely used on typical Ontario soils without adversely affecting crop yields or nitrate and heavy metal content.

4.2 Materials and Methods

4.2.1 General

Experiments have been in progress since 1973 on two soils, a Conestoga loam at the Elora Research Station and a Caledon loamy sand at the Cambridge (Hespeler) Research Station. At the Elora Research Station one experiment is in progress with corn (*Zea mays L.*) as the crop and one with bromegrass (*Bromis inermis Leyess*). Only corn is being grown at the Cambridge site.

The sources of nitrogen used in these trails were ammonium nitrate and combined waste activated primary and secondary fluid digested sewage sludges resulting from calcium hydroxide, aluminum sulphate and ferric chloride treatment of sewage for phosphorus removal. Chemical compositions of sludges used in 1976 are presented in Table 13, and the amounts of various constituents applied in the sludges are presented in Tables 14 to 19. The Newmarket sewage treatment plant switched from calcium to iron for phosphorus removal during the year, and iron treated Newmarket sludge was used in error on calcium treatments of the Elora corn trial and for the first application in the Elora bromegrass trial (Table 13).

The rates of nitrogen application each year from ammonium nitrate were: 0, 89, 178 and 356 lb N/ac (0, 200 and 400 kg N/ha). The rates from each of the three sewage sludges were: 178, 356, 712 and 1424 lb N/ac (200, 400, 800 and 1600 kg N/ha).

There were four nitrogen sources, four rates, and three replicateons resulting in a total of 48 plots for each trail. The corn plot size was 15' x 25' (4.57 x 7.62 m) and the bromegrass plot size was 8' x 20' (2.44 x 6.09 m).

4.2.2 Bromegrass, Elora

The bromegrass trial was laid out on an established stand of bromegrass on the Elora Research Station on Conestoga loam in the spring of 1973. Potassium chloride supplying 50 lb K_2O/ac (47 kg K/ha) was broadcast on all plots in the spring of 1973, and supplied 97 lb of K_2O/ac (90 kg K/ha) in the spring of 1974, 1975 and 1976. Eighty-three lb P_2O_5/ac (40 kg P/ha) as 46% superphosphate was broadcast on the plots which did not receive sludge in the spring of 1973, 80 lb P_2O_5/ac (39 kg P/ha) in the spring of 1974 and 83 lb P_2O_5/ac (40 kg P/ha) in the spring of 1975 and again in 1976. Annual nitrogen rates for the bromegrass were divided into three equal applications for both the ammonium nitrate and sewage sludges. The dates of nitrogen and sludge application to grass are presented, along with harvest dates, in Table 20 and the amounts of nutrients and metals added in the sludges are presented in Tables 14 and 15. To reduce costs only the first cut of bromegrass was analyzed chemically, and only selected treatments were analyzed for Mo, Se and Hg.

4.2.3 Corn, Elora and Cambridge

The two corn trials have been in progress since the fall of 1972 when an old stand of bromegrass was plowed under at the Elora Research Station, and an oat cover crop was plowed under at the Cambridge site. Field operations in 1976 are listed in Table 21, the chemical composition of the sludges used are described in Table 13 and the amounts of nutrients and metals added in the sludges are presented in Tables 16, 17, 18 and 19.

In order to reduce costs, and because corn grain samples showed few differences in chemical composition in previous years, corn grain samples from only two ammonium nitrate rates and the highest rates of sewage sludges were analyzed chemically. To save costs only selected treatments of the corn stover were analyzed for Mo, Se and Hg.

4.3 Results and Discussion

4.3.1 The 1976 season

In 1976 April was warmer than normal allowing an early start to plowing and sludge application. Early May was cool and wet, however, with the result that seeding dates were about normal. Emergence of corn and final stands were adequate in spite of a dry spell during germination and emergence. The moisture supply was better than usual in 1976 with few prolonged dry periods. While there were few hot periods in the summer, the normal total number of heat units were available for the crop. Because of the plentiful moisture supply both hay and corn yields were above average. The Cambridge corn experiment in particular suffered less than usual from dry weather.

In general only the 1976 data are discussed in this report as the 1973, 74 and 75 results are discussed in previous reports. With the exception of crop yields, data for different treatments are presented only where there were significant treatment effects. Where there were no treatment differences in chemical composition, only the trial averages are presented.

Bromegrass yields for the three cuttings in 1976 are presented in Tables 22, 23 and 24 and the total annual yields for 1976, 75 and 74 in Tables 25, 26 and 27. In 1976, as in previous years, the first cutting made up a very large portion of the total bromegrass yield for the season (approximately 68%). Sewage sludge appears to have produced somewhat higher yields than the same rate of nitrogen from ammonium nitrate (Table 25). The calcium sludge appears to have produced a different response pattern from the iron sludge, but this is difficult to interpret as the first application of sludge on the "calcium" sludge plots in 1976 was actually iron sludge (Table 13).

Corn stover yields at Elora and Cambridge were not affected by treatment in 1976 (Tables 28 and 29).

Corn grain yields were increased significantly by application of ammonium nitrate or of sludge at both Elora and Cambridge (Tables 30 and 31). The "calcium" sludge treatment produced lower yields than the other sludges at Elora but, as with the bromegrass, the sludge applied in 1976 was actually an iron sludge (Table 13).

Nitrogen concentration in the bromegrass (Table 32) and in the corn stover (Tables 33 and 34) were higher with ammonium nitrate than with the equivalent rate of nitrogen from sludge. In the bromegrass it is possible that the greater yields with sludge than with ammonium nitrate may account for the difference in nitrogen concentration. Nitrogen concentration in the corn grain was not affected by treatment (Table 35).

Nitrate-N concentration in the bromegrass and corn stover increased with rate of nitrogen from ammonium nitrate and from sludge.

Phosphorus concentration in bromegrass was higher with sludge than with ammonium nitrate (Table 39). In the corn stover and corn grain, phosphorus concentration was little affected by treatment (Tables 40, 41 and 35).

Soil phosphorus extractable by sodium bicarbonate was markedly increased by sludge application in all three experiments (Tables 42, 43 and 44). This effect was much more marked with the calcium sludge than with aluminum or iron.

Potassium concentration in bromegrass was reduced by nitrogen application (Table 45). At least in part this is believed to be due to dilution by the increased growth obtained with nitrogen. Potassium concentration in corn stover at Elora increased slightly with increased rate of nitrogen (Table 46). Corn grain potassium was not significantly affected by treatment (Table 35).

Soil potassium extracted with ammonium acetate was not greatly affected by treatment except at the Cambridge site (Table 49) where the calcium sludge resulted in lower extractable potassium levels.

Calcium concentration in the bromegrass (Table 50) and in the Cambridge corn stover (Table 51) were increased by increased rates of nitrogen from ammonium nitrate and from sewage sludge.

Soil pH has been increased by lime sludge application in all three trials (Tables 52, 53 and 54) to pH levels higher than those of the lime sludge or the original soil. The iron sludge decreased soil pH slightly in the bromegrass and Elora corn trails.

Magnesium concentration in bromegrass was increased by nitrogen application from ammonium nitrate or from sludge (Table 55) but this effect was not apparent in the corn stover (Tables 56 and 57).

Soil magnesium extracted with ammonium acetate from the Elora corn experiment was increased by application of iron sludge but not by the other sludges (Table 58). This trend is not apparent in the other two trials and is not understood.

Manganese concentration in bromegrass was reduced by the highest rate of calcium sludge (Table 59). Manganese concentration in corn stover from Elora was reduced by high rates of ammonium nitrate (Table 60).

Iron concentration in bromegrass was increased slightly but significantly by increased nitrogen rates from ammonium nitrate or from sludge (Table 61).

Boron concentration in the bromegrass was decreased very slightly by nitrogen from ammonium nitrate or from sewage sludge (Table 62).

Cadmium concentration in bromegrass was rather variable but treatment differences were not significant (Table 63). Cadmium concentration in corn stover at Elora and Cambridge increased with increasing rates of nitrogen from ammonium nitrate or sludge but was highest with the highest rates of aluminum and iron sludge (Tables 64 and 65). Cadmium concentration in the corn grain at Elora may have been increased slightly by sludge application (Table 66).

Cadmium concentrations in ryegrass and corn stover for the period 1973 to 1976 from selected treatments are presented in Tables 67 and 68. The values are rather variable from year to year, but there appears to be some increase in cadmium concentration in the bromegrass and in corn stover over the four-year period with ammonium nitrate and a greater increase with sewage sludge.

Chromium concentration in the bromegrass appeared to be lower with the highest rate of calcium sludge than with some other treatments (Table 69). Chromium concentration in the corn stover from Cambridge was much higher with the two highest rates of aluminum sludge than with other treatments (Table 70). Chromium concentration was actually lower in the grain with the high rate of aluminum sludge at both Elora and Cambridge, (Table 66). The aluminum sludge supplied a great deal more chromium than either of the other sludges in all three experiments (Tables 15, 17 and 19).

Copper concentration in the bromegrass and in corn stover from both experiments was increased by ammonium nitrate or sewage sludge (Tables 71, 72 and 73). The copper concentration was higher with higher rates of sludge than with the highest rate of ammonium nitrate in the bromegrass and in the corn stover at Cambridge, but only with the iron sludge in the latter experiment. Copper concentration in corn grain was highest with the high rate of calcium sludge at Cambridge but not affected by treatment at Elora (Table 66).

Copper concentrations in ryegrass and corn stover for the period 1973 to 1976 from selected treatments are presented in (Tables 74 and 75). There does not appear to be any increase in copper concentration in the three crops from year to year even with the highest rate of sludge application.

Nickel concentration in bromegrass was greater with high rates of aluminum sludge than with other treatments (Table 76) but in the corn stover from Cambridge it was highest with the calcium sludge (Table 27). Corn grain nickel concentrations were not affected by treatment, (Table 66).

Lead concentration in the bromegrass appeared to be slightly higher with high rates of calcium sludge (Table 78).

Zinc concentration in bromegrass and in corn stover in both trials increased with increasing rates of application of all three sludges (Tables 79, 80 and 81). In the bromegrass and in the corn stover from Cambridge, zinc concentration was also increased, but to a lesser extent, by ammonium nitrate. The calcium sludge increased zinc concentration less than the aluminum and iron sludges in the corn stover, but the calcium and aluminum sludges produced similar results in the bromegrass. There appeared to be some influence of aluminum and iron sludge on the zinc concentration in corn grain from Elora (Table 66).

Zinc concentrations in ryegrass and corn stover for the period 1973 to 1976 from selected treatments are presented in Tables 82 and 83. There does not appear to be any increase in zinc concentration in the bromegrass from year to year, and the corn stover data from Cambridge are quite variable so that it is difficult to determine if there is a pattern. There appears to be an increase in zinc concentration in the Elora corn stover from year to year, however, with all three sludges applied at the 1600 kg N/ha rate.

Molybdenum concentration in bromegrass was not affected by treatment (Table 84). In corn stover from both Elora and Cambridge, however, the molybdenum concentration was increased by the calcium sludge (Table 85). This may be due to the higher soil pH resulting from the calcium sludge.

Selenium concentration in bromegrass and in corn grain from Elora appears to have been reduced by aluminum sludge (Tables 84 and 85) but was not affected by treatment in corn stover from either site or in corn grain from Cambridge.

Mercury concentration in bromegrass and corn stover and grain was not affected by treatment (Tables 84 and 85).

Other nutrients and metal concentrations in corn stover which were not affected by treatment are presented in Table 86.

4.4 Soil Nutrients and Metals Extracted With Aqua Regia and NTA

In April of 1976, before sludge addition, soils in the bromegrass experiment were systematically sampled at 0-2, 2-4 and 4-6 inch depths (0-5, 5-10 and 10-15 cm). Sixteen cores were taken with a soil sampling tube from each experimental plot and were thoroughly mixed before subsampling and analysis. The corn trials at Elora and Cambridge were ploughed and tilled, so were only sampled at the 0-6 inch (0-15 cm) depth.

Aqua regia was used to extract nutrients and metals from these samples. "Plant available" cadmium, nickel and zinc were also extracted from these samples with NTA (nitrilotriacetic acid, 25 m M at pH 6.0).

The object of this part of the investigation was to determine whether the nutrients and metals applied over the three previous years could be recovered, and to determine the extent to which the metals moved downward in the soil.

4.4.1 Bromegrass experiment

Phosphorus recovery in aqua regia was approximately 100% of that applied (Table 87). Only with the Ca-sludge was there any evidence of P movement below 2 inches (5 cm).

Calcium recovery was erratic (Table 88), but over 100% in the two treatments supplying the most Ca. Calcium appears to have moved at least as far down as the 4-6 inch (10-15 cm) depth with the Ca sludge but movement was not detected with the lower rates of Ca supplied by the other two sludges.

Aluminum and iron recovery was erratic (Tables 89 and 90), probably due to the small amount of added aluminum and iron in relation to amounts originally present in the soil. There was no evidence of aluminum or iron movement. The fraction of Fe and Al extracted with aqua regia is probably appreciably less than the total content in the soil.

Manganese in the aqua regia extract was no higher from the sludge treated soil than from soil receiving NH_4NO_3 (Table 91).

Cadmium applied in the sludge was recovered in the aqua regia extract to a variable extent (Table 92). About half as much cadmium was extracted with NTA as with aqua regia (Table 93) but there was a tendency for NTA to extract a larger fraction of aqua regia soluble Cd on the soil which did not receive sewage sludge. There appears to have been some movement of cadmium down as far as the 4-6 inch (10-15 cm) soil layer, and a portion of this cadmium is soluble in NTA and hence probably available to plants.

Chromium recovery in the aqua regia extract was very variable (Table 94). With the Al-sludge chromium appears to have moved into the 4-6 inch (10-15 cm) soil layer.

Copper applied in the sludge was recovered in the aqua regia extract to a variable extent (Table 95). There is some evidence of copper movement into the 2-4 inch (5-10 cm) soil layer with two of the three sludges.

Lead applied in the sludges was recovered in the aqua regia extracts (Table 96). There is some evidence of lead movement into the 2 to 4 inch (5-10 cm) soil layer and perhaps into the 4 to 6 inch (10-15 cm) soil layer.

Nickel recovery in the aqua regia extract was very variable (Table 97). There was no indication of metal movement from the aqua regia data, but it appears from the NTA extractable nickel (Table 98) that there may have been some movement into the 2-4 inch (10-15 cm) layer. A larger fraction of the aqua regia-extractable nickel was NTA-extractable in the sludge treated plots than in those receiving NH_4NO_3. The opposite was true with cadmium.

Zinc recovery in aqua regia was relatively consistent across the three sludges but was over 100%. There is some evidence of zinc movement into the 2-4 inch (10-15 cm) soil layer but this trend was not significant statistically (Table 99). As with nickel, a larger fraction of the aqua regia extractable soil zinc was NTA extractable in the sludge treatments than in those receiving NH_4NO_3.

Mercury recovery in the aqua regia extract (Table 101) was well under 100%, and it seems probable that some losses occurred due to volatilization or leaching. Mercury moved into the 4-6 inch (10-15 cm) layer where the Fe-sludge was applied, and to a lesser extent with the other two sludges.

Recovery of metals and nutrients with aqua regia was rather erratic in most cases, and there appear to be several causes for the poor measure of recovery. Some metals such as aluminum and iron may not have been brought into solution by the aqua regia. In some cases the metal extractions were quite reproducible on the NH_4NO_3 treatments but very erratic on the treatments receiving high rates of sewage sludge. This occurred chiefly where the sludge treatments produced much higher readings than the NH_4NO_3 treatment and where there was little indication of metal movement in the soil. It is believed that in these cases the metal from sludge was not uniformly distributed in the soil, and that insufficient soil samples were taken to obtain a good measure of the metal content of treatments receiving high rates of sludge. In some cases the amounts of metal added were small in relation to the total amount in the soil leading to poor precision in measuring recovery of the applied metal.

With the possible exception of mercury it does not appear that the metals and nutrients studied have moved below the 6 inch (15 cm) soil depth in this study.

4.4.2 Corn trials

Metals extracted from the 0-6" soil layer sampled in April, 1976, in the Elora and Cambridge corn experiments are presented in Tables 102 and 103. As discussed regarding the bromegrass experiment, the agreement between amounts of metals added to the soils and amounts extracted by aqua regia is not very good. A large part of the problem is believed to be that of obtaining a representative sample of field plots which have received high rates of sludge application.

NTA-extractable soil cadmium, nickel and zinc from Elora and Cambridge corn trials are presented in Table 104. Over half of the aqua regia-extractable Cd was extractable with NTA. The proportion of the aqua regia-extractable Ni extracted with NTA was much lower, about 10 to

20%. About 20 to 60% of the amount of aqua regia-extractable zinc was extracted with NTA, the higher figure being with the largest additions of zinc in sewage sludge.

It is not intended to measure soil metals each year in these trials. It is obvious, however, that when metal content is measured considerably more detailed sampling will be required on the sludge treated plots.

TABLE 13. Chemical Composition of Sludges Obtained from Treatment Plants on Various Dates (fluid weight basis)

Sludge	Load* No.	Treatment Plant	Date	pH	D.M.	Total N	Sol. & Exch. NH_4-N	P	K	Ca	Mg	Na	Al	Fe
										%				
Calcium	1	Newmarket**	14/4/76	7.2	2.71	0.14	0.040	0.06	0.01	0.26	0.02	0.014	0.009	0.11
	2	Midland	14/5/76	7.5	2.75	0.06	0.014	0.05	0.005	0.36	0.03	0.008	0.030	0.033
	3	Midland	15/6/76	7.4	11.2	0.10	0.019	0.21	0.007	1.98	0.14	0.027	0.085	0.096
	4	Midland	21/7/76	7.4	7.83	0.10	0.015	0.15	0.007	1.62	0.083	0.008	0.056	0.071
Aluminum	5	Guelph	16/4/76	7.5	3.50	0.17	0.06	0.12	0.01	0.28	0.02	0.015	0.11	0.10
	6	Guelph	22/4/76	7.3	5.22	0.23	0.08	0.18	0.01	0.33	0.03	0.017	0.21	0.16
	7	Guelph	14/6/76	7.7	3.70	0.15	0.05	0.13	0.009	0.24	0.03	0.021	0.15	0.11
	8	Guelph	21/7/76	7.5	1.99	0.10	0.02	0.07	0.01	0.13	0.01	0.011	0.06	0.04
Iron	9	N. Toronto	13/4/76	7.3	4.98	0.28	0.08	0.19	0.02	0.24	0.03	0.017	0.033	0.36
	10	N. Toronto	21/4/76	7.5	4.50	0.27	0.10	0.19	0.02	0.24	0.03	0.016	0.028	0.32
	11	N. Toronto	14/6/76	7.4	5.59	0.27	0.10	0.22	0.016	0.22	0.04	0.022	0.062	0.39
	12	N. Toronto	21/7/76	7.5	3.28	0.18	0.05	0.13	0.02	0.13	0.016	0.007	0.034	0.13

* Loads number 1, 5 & 9 were used on the 1st 1976 application to the bromegrass trial and to the Elora corn trial.
Loads number 2, 6 & 10 were used on the Cambridge corn trial.
Loads number 3, 7 & 11 were used on the 2nd 1976 application to the bromegrass trial.
Loads number 4, 8 and 12 were used on the 3rd 1976 application to the bromegrass trial.

** Ferric chloride treatment.

TABLE 13 (Cont'd)

Sludge	Treatment Plant	Date	Cd	Cr	Cu	Mn	Mo	Ni	Pb	Zn	Hg	Se	B
			----------------					µg/g					----------------
Calcium	Newmarket	14/4/76	0.37	3.5	16.3	21.9	0.53	0.54	19.2	92	0.14	0.15	0.60
	Midland	14/5/76	0.17	37	19.3	8.3	0.46	66	12.5	61	0.24	0.04	1.07
	Midland	15/6/76	0.50	78	39.0	28.0	2.78	238	39.2	162	0.86	0.11	2.58
	Midland	21/7/76	0.33	45	22.7	17.6	0.65	143	13.7	108	0.61	0.08	1.88
Aluminum	Guelph	16/4/76	2.72	58	77	10.2	1.55	3.0	49	161	0.22	0.14	0.77
	Guelph	24/4/76	4.45	94	125	12.5	2.32	4.7	89	253	0.49	0.16	1.04
	Guelph	14/6/76	3.33	69	84	10.0	1.67	3.1	62	204	0.27	0.14	0.96
	Guelph	21/7/76	1.45	28	29	4.1	0.87	1.5	25	72	0.13	0.08	0.58
Iron	N. Toronto	13/4/76	1.11	23	72	22.9	1.65	1.49	105	197	1.08	N.D†	0.65
	N. Toronto	21/4/76	1.08	21	68	21.2	1.75	1.35	99	171	1.10	N.D	0.81
	N. Toronto	14/6/76	1.26	34	76	22.5	2.78	0.98	108	196	1.12	N.D	0.95
	N. Toronto	21/7/76	0.69	14	26	12.6	1.33	0.66	49	89	0.61	N.D.	0.52

† Not detected (<2ppb)

TABLE 14. Total Amounts of Various Constituents in Sludges Added to Bromegrass Experiment in First Application and Total of Three Applications at 200 kg N/ha/annum. Elora, 1976.

Constituent	Ca-sludge		Al-sludge		Fe-sludge	
	1st Application	Total	1st Application	Total	1st Application	Total
	kg/ha					
Dry matter	1,290	14,000	1,373	4,344	1,186	3,780
Total N	66.7	200	66.7	200	66.7	200
Soluble & Exch. NH_4-N	19	42	24	57	19	63
P	29	269	47	152	45	148
K	4.8	14.2	3.9	14.6	4.8	16.1
Ca	124	2,524	110	301	57	160
Mg	9.5	156	7.8	27.4	7.1	22.4
Na	6.7	30	5.9	22.5	4.1	12.2
Al	4.3	98	43	151	7.9	36
Fe	52	163	38	111	85.5	230
Mn	1.0	7.8	0.40	1.11	0.55	1.57
Cd	0.018	0.07	0.11	0.35	0.026	0.083
Cr	0.17	8.4	2.3	7.2	0.55	1.93
Cu	0.78	4.9	3.0	8.7	1.7	4.6
Mo	0.025	0.25	0.06	0.19	0.039	0.16
Ni	0.026	25.4	0.12	0.36	0.035	0.083
Pb	0.91	4.4	1.9	6.3	2.5	7.0
Zn	4.4	22.4	6.3	20.2	4.7	12.8
Hg	0.007	0.11	0.009	0.030	0.026	0.077
Se	0.007	0.02	0.005	0.017	<0.0002	<0.0006
B	0.029	0.33	0.030	0.112	0.015	0.058

TABLE 15. Total Amounts of Various Constituents Applied to Bromegrass Experiment in Sludges at 178 lb N/ac (200 kg N/ha), 1973 to 1976 Inclusive.

Constituents	Calcium Sludge		Aluminum Sludge		Iron Sludge	
	lb/ac	(kg/ha)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
Dry matter	41,700	46,800	16,700	18,700	15,000	16,800
Total N	714	800	714	800	714	800
Soluble & Exch. NH_4-N	171	192	244	273	229	257
P_2O_5	1,350		1,300		1,540	
P		660		632		749
K_2O	71		65		73	
K		66		60		68
Ca	8,460	9,480	946	1,060	615	690
Mg	288	323	110	124	102	114
Na	98	110	88	99	41	46
Al	178	199	767	860	208	233
Fe	351	394	201	225	798	895
Mn	19.9	21.4	3.1	3.5	6.3	7.1
Cd	0.18	0.20	0.42	0.47	0.31	0.35
Cr	8.4	9.4	65	73	6.7	7.5
Cu	10.8	12.1	16.1	18.1	20.4	22.9
Ni	23.3	26.1	3.4	3.8	0.52	0.58
Pb	7.3	8.2	10.2	11.4	26.6	29.8
Zn	44	49	59	66	46	52
Mo	0.23	0.26	0.18	0.20	0.25	0.28
Hg	0.16	0.18	0.06	0.07	0.30	0.34
Se	0.029	0.032	0.061	0.068	<0.001	<0.001
B	0.96	1.06	0.46	0.52	0.36	0.40

TABLE 16. Amounts of Various Constituents Added in Sludges in 1976 at 178 lb N/ac (200 kg N/ha) to Corn Experiment at Elora.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Solids	3453	(3871)	3673	(4118)	3176	(3557)
Total N	178	(200)	178	(200)	178	(200)
Soluble + Exch NH_4-N	51	(57)	63	(71)	51	(57)
P_2O_5	185		303		278	
P		(86)		(141)		(136)
K_2O	15		13		15.4	
K		(14)		(12)		(14)
Ca	331	(371)	293	(329)	153	(171)
Mg	26	(29)	21	(24)	19	(21)
Na	18	(20)	16	(18)	11	(12)
Al	11.6	(13)	115	(129)	21.5	(24)
Fe	140	(157)	105	(118)	229	(257)
Mn	2.8	(3.1)	1.1	(1.2)	1.5	(1.64)
Cd	0.045	(0.05)	0.29	(0.32)	0.07	(0.08)
Cr	0.45	(0.50)	6.1	(6.8)	1.46	(1.64)
Cu	2.08	(2.33)	8.1	(9.1)	4.6	(5.14)
Ni	0.07	(0.08)	0.31	(0.35)	0.10	(0.11)
Pb	2.44	(2.74)	5.2	(5.8)	6.7	(7.5)
Zn	11.7	(13.1)	17	(19)	13.0	(14.1)
B	0.08	(0.09)	0.08	(0.09)	0.04	(0.05)
Hg	0.018	(0.02)	0.023	(0.026)	0.071	(0.077)
Se	0.019	(0.021)	0.014	(0.016)	<0.0002	(<0.0002)
Mo	0.07	(0.08)	0.16	(0.18)	0.11	(0.12)

TABLE 17. Total Amounts of Various Nutrients and Metals Added to Elora Corn Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1976.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Solids	32,600	(36,600)	15,900	(17,800)	14,900	(16,700)
Total N	712	(800)	712	(800)	712	(800)
Soluble & exch. NH_4-N	237	(266)	264	(297)	229	(257)
P_2O_5	880		13 00		1516	
P		(425)		(626)		(740)
K_2O	94		57		74	
K		(88)		(54)		(69)
Ca	6,490	(7,290)	801	(900)	598	(671)
Mg	185	(208)	107	(121)	97	(109)
Na	66	(74)	63	(71)	46	(51)
Al	126	(141)	565	(635)	145	(162)
Fe	374	(420)	165	(185)	962	(1080)
Mn	15	(16)	3.2	(3.6)	6.5	(7.2)
Cd	0.12	(0.13)	0.37	(0.42)	0.34	(0.38)
Cr	1.32	(1.48)	58	(65)	6.2	(6.9)
Cu	7.1	(7.9)	16.2	(18.2)	21.6	(23)
Ni	0.91	(1.02)	2.8	(3.2)	0.46	(0.51)
Pb	6.1	(6.9)	9.0	(10.1)	28	(31.5)
Zn	36	(40)	51	(57)	47	(52)
B	0.36	(0.38)	0.19	(0.21)	0.32	(0.36)
Hg	0.068	(0.08)	0.063	(0.07)	0.30	(0.34)
Mo	0.22	(0.25)	0.30	(0.34)	0.47	(0.52)
Se	0.022	(0.024)	0.032	(0.036)	0.001	(0.001)

TABLE 18. Amounts of Various Constituents Added in Sludges in 1976 at 178 lb N/ac (200 kg N/ha) to Corn Experiment at Cambridge.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Solids	8,177	(9,167)	4,049	(4,539)	2,976	(3,333)
Total N	178	(200)	178	(200)	178	(200)
Soluble + Exch NH_4-N	42	(47)	68	(76)	66	(74)
P_2O_5	359		338		303	
P		(167)		(157)		(141)
K_2O	18		9.4		16	
K		(17)		(8.7)		(15)
Ca	1,070	(1,200)	256	(287)	159	(178)
Mg	89	(100)	23	(26)	20	(22)
Na	24	(27)	13	(15)	11	(12)
Al	89	(100)	163	(183)	19	(21)
Fe	98	(110)	124	(139)	212	(237)
Mn	2.5	(2.8)	1.0	(1.1)	1.4	(1.6)
Cd	0.05	(0.06)	0.35	(0.39)	0.07	(0.08)
Cr	11.0	(12.3)	7.3	(8.2)	1.4	(1.6)
Cu	5.7	(6.4)	9.7	(10.9)	4.5	(5.0)
Ni	20	(22)	0.37	(0.41)	0.09	(0.10)
Pb	3.7	(4.2)	6.9	(7.7)	6.5	(7.3)
Zn	18	(20)	20	(22)	11.3	(12.7)
B	0.32	(0.36)	0.08	(0.09)	0.05	(0.06)
Hg	0.07	(0.08)	0.038	(0.43)	0.072	(0.081)
Se	0.012	(0.013)	0.012	(0.013)	<0.0002	(<0.0002)
Mo	0.13	(0.15)	0.18	(0.20)	0.12	(0.13)

TABLE 19. Total Amounts of Various Nutrients and Metals Added to Cambridge Corn Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1976.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Solids	45,000	(50,500)	17,400	(19,500)	14,900	(16,700)
Total N	714	(800)	714	(800)	714	(800)
Soluble & exch. NH_4-N	178	(199)	260	(291)	250	(280)
P_2O_5	1,116		1,305		1,561	
P		(565)		(638)		(762)
K_2O	79		46.5		66	
K		(74)		(44)		(62)
Ca	9,285	(10,400)	946	(1,060)	570	(638)
Mg	221	(248)	121	(135)	102	(114)
Na	73	(82)	62	(69)	50	(56)
Al	187	(210)	1,402	(1,570)	164	(184)
Fe	296	(332)	257	(288)	946	(1,060)
Mn	16	(18)	3.3	(3.7)	6.6	(7.4)
Cd	0.21	(0.23)	0.49	(0.55)	0.30	(0.34)
Cr	12.7	(14.2)	71	(80)	13.0	(14.6)
Cu	12.2	(13.7)	18	(20.2)	20.5	(23)
Ni	20.6	(23.1)	3.6	(4.0)	0.89	(1.0)
Pb	8.5	(9.5)	11.5	(12.9)	25.3	(28.3)
Zn	45	(50)	61	(68)	49	(55)
B	0.58	(0.65)	0.38	(0.43)	0.22	(0.25)
Hg	0.13	(0.15)	0.07	(0.08)	0.26	(0.29)
Mo	0.29	(0.32)	0.32	(0.36)	0.69	(0.77)
Se	0.014	(0.016)	0.030	(0.034)	<0.001	(<0.001)

TABLE 20. Dates of Sludge and Nitrogen Fertilizer Application and Forage Harvest. Bromegrass Experiment at Elora, 1976.

Operation		Cut 1	Cut 2	Cut 3
NH_4NO_3	Addition	April 13	June 17	July 22
Ca-sludge	Addition	April 14	June 16	July 22
Al-sludge	Addition	April 16	June 15	July 22
Fe-sludge	Additon	April 13	June 15	July 22
Harvest		June 9	July 21	Sept. 3

TABLE 21. Field Operations on Rate and Source of Sludge Experiments with Corn, 1976.

Treatment or Description	Elora	Cambridge
Soil	Conestoga loam	Caledon loamy sand
Plowed	April 12	April 9
Calcium sludge applied	April 14	May 12 and 14
Iron sludge applied	April 13	April 21
Alum sludge applied	April 16 and 17	April 22
Phosphate applied to ammonium nitrate plots and disked in before seeding	104 lb P_2O_5/ac (50 kg P/ha)	No phosphate required
Potassium applied to all treatments and disked in before seeding	97 lb K_2O/ac (90 kg K/ha)	43 lb K_2O/ac (40 kg K/ha)
Seeding (60 lb of 6-18-6 liquid fertilizer per acre banded with seed on all treatments)	May 13	May 22
Emerged plants counted	June 7	June 18
Thinning and sampling* of seedlings	June 17	June 18
Silk and final stand counts	August 4	August 3
Final stand (plants/ac)	23,000	16,000
Plant height to flag leaf measurement	August 24	August 25
Count of lodged plants	October 8	September 23
Grain harvested	October 8	September 23
Stover harvested	October 28	October 21

* Five to seven leaf stage

TABLE 22. Dry Matter Yield of First Cut (June 9), Bromegrass. Elora, 1976

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	lb/ac (kg/ha)				
0 (0)	1730 (1940) a				
89 (100)	3630 (4070) bc				
178 (200)	4040 (4530) bcd	4240 (4750) bcde	3480 (3900) b	4070 (4560) bcd	3930 (4400)
356 (400)	4520 (5070) cdef	5040 (5650) ef	4860 (5450) def	4210 (4710) bcde	4700 (5270)
712 (800)		4650 (5210) def	4420 (4960) cdef	4500 (5050) cdef	4520 (5070)
1424 (1600)		4190 (4700) bcde	5110 (5720) ef	5180 (5810) f	4830 (5410)
Average		4530 (5080)	4470 (5010)	4490 (5030)	4490 (5040)

C.V. = 11.1%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability and the source-rate interaction at 0.05 probability by "F" test.

TABLE 23. Dry Matter Yield of Second Cut (July 21), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	lb/ac (kg/ha)				
0 (0)	740 (820) a				
89 (100)	1500 (1680) bcde				
178 (200)	1390 (1550) bcd	1280 (1430) b	1350 (1510) bcd	1730 (1930) e	1450 (1630)
356 (400)	1350 (1510) bc	1590 (1780) bcde	1590 (1790) cde	1660 (1860) de	1610 (1810)
712 (800)		1530 (1720) bcde	1560 (1750) bcde	1350 (1520) bcd	1480 (1660)
1424 (1600)		1700 (1910) e	1640 (1840) cde	1520 (1700) bcde	1620 (1820)
Average		1530 (1710)	1540 (1720)	1560 (1750)	1540 (1730)

C.V. = 10.8%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

The sludge source-rate interaction is significant at 0.05 probability by "F" test.

TABLE 24. Dry Matter Yield of Third Cut (September 3), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		lb/ac (kg/ha)			
0 (0)	270 (310) a				
89 (100)	490 (550) abcd				
178 (200)	590 (660) abcd	780 (880) d	520 (580) abcd	460 (510) abc	590 (660)
356 (400)	500 (560) abcd	690 (770) bcd	560 (620) abcd	400 (450) ab	550 (620)
712 (800)		620 (700) bcd	460 (510) abcd	740 (830) cd	610 (680)
1424 (1600)		560 (630) abcd	370 (410) ab	500 (560) abcd	470 (530)
Average		660 (740)	480 (530)	530 (590)	550 (620)

C.V. = 31.3%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Source of sludge is significant at 0.05 probability level by 'F' test.

TABLE 25. Total Dry Matter Yield of Bromegrass (Three Cuts). Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		lb/ac (kg/ha)			
0 (0)	2740 (3070) a				
89 (100)	5620 (6300) bc				
178 (200)	6020 (6750) bcd	6300 (7070) bcde	5350 (6000) b	6250 (7000) bcde	5970 (6690)
356 (400)	6370 (7140) cdef	7320 (8200) f	7010 (7860) def	6270 (7030) bcde	6870 (7700)
712 (800)		6800 (7620) def	6440 (7210) cdef	6600 (7400) cde	6610 (7410)
1424 (1600)		6450 (7230) cdef	7120 (7980) ef	7200 (8070) ef	6920 (7760)
Average		6720 (7530)	6480 (7260)	6580 (7370)	6590 (7390)

C.V. = 8.4%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability and the source-rate interaction at 0.05 probability by "F" test.

TABLE 26. Annual Dry Matter Yield of Bromegrass (Three Cuts). Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		lb/ac (kg/ha)				
0	(0)	1497(1679)^{h*}				
89	(100)	4465(5005)^{fg}				
178	(200)	5591(6268)^{de}	3764(4220)^{g}	4974(5576)^{ef}	5007(5614)^{ef}	4582(5136)
356	(400)	6065(6799)^{cd}	5620(6301)^{de}	6675(7483)^{bc}	6441(7220)^{bc}	6245(7001)
712	(800)		7088(7947)^{ab}	7148(8013)^{ab}	6972(7816)^{ab}	7069(7925)
1424	(1600)		7544(8458)^{a}	6853(7683)^{ab}	7232(8108)^{ab}	7210(8083)
Average		4405(4938)	6004(6731)	6412(7189)	6413(7189)	6276(7036)

C.V. = 7.8%

*individual treatments not followed by a common letter are significantly different at 0.05 probability.

Level of significance of various effects by "F" test.

Effect	Level
Sources of sludge	N.S.
Rates of sludge	0.01
Sludge x rate interaction	0.05
Rates of ammonium nitrate	0.01

TABLE 27. Annual Dry Matter Yield of Bromegrass (Three Cuts). Elora, 1974.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		dry matter - lb/ac (kg/ha)				
0	(0)	890 (990)^{a}*				
89	(100)	2750 (3080)^{bc}				
178	(200)	4120 (4620)^{cf}	2160 (2420)^{b}	3220 (3600)^{cd}	3060 (3430)^{cd}	2810 (3150)
356	(400)	6030 (6750)^{h}	3650 (4090)^{de}	4820 (5410)^{g}	4770 (5340)^{fg}	4410 (4950)
712	(800)		6340 (7100)^{h}	6060 (6790)^{h}	6240 (6990)^{h}	6210 (6960)
1424	(1600)		6990 (7840)^{i}	6150 (6896)^{h}	5960 (6680)^{h}	6370 (7140)
Average**			4790 (5360)	5060 (5680)	5010 (5610)	4950 (5550)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

Rates of sludge and of ammonium nitrate are significantly different at 0.01 probability by "F" test.

Source x rate interaction is significant at 0.01 probability level.

TABLE 28. Effect of Rate and Source of Nitrogen on Corn Stover Yield from Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		lb/ac (kg/ha)			
0 (0)	2930 (3290) b*				
89 (100)	3620 (4060) ab				
178 (200)	3020 (3380) ab	3640 (4070) ab	3230 (3610) ab	3320 (3720) ab	3400 (3800)
356 (400)	2890 (3240) b	2960 (3320) b	2950 (3310) b	2910 (3260) b	2940 (3300)
712 (800)		3250 (3640) ab	3130 (3500) ab	3760 (4210) a	3380 (3780)
1424 (1600)		3100 (3470) ab	3270 (3660) ab	3280 (3680) ab	3220 (3600)
Average		3240 (3630)	3140 (3520)	3320 (3720)	3230 (3620)

* Individual treatments followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

There were no significant differences between treatment effects by 'F' test.

C.V. = 12%

TABLE 29. Effect of Rate and Source of Nitrogen on Corn Stover Yield from Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			lb/ac (kg/ha)		
0 (0)	2650 (2970)*				
89 (100)	2660 (2980)				
178 (200)	2580 (2890)	2570 (2880)	2550 (2850)	2690 (3010)	2600 (2910)
356 (400)	2530 (2830)	2610 (2920)	2550 (2850)	2940 (3290)	2700 (3020)
712 (800)		2570 (2880)	2370 (2660)	2430 (2720)	2460 (2750)
1424 (1600)		2580 (2890)	2550 (2850)	2490 (2790)	2540 (2840)
Average		2580 (2890)	2500 (2800)	2640 (2950)	2570 (2880)

* There were no treatment differences.

C.V. = 14%

TABLE 30. Effect of Rate and Source of Nitrogen on Corn Grain Yield from Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			lb/ac (kg/ha)		
0 (0)	5730 (6420) e*				
89 (100)	6660 (7460) a-d				
178 (200)	6160 (6900) c-e	6290 (7050) b-e	6740 (7540) a-d	6560 (7350) a-d	6530 (7320)
356 (400)	6150 (6890) c-e	6050 (6770) d-e	6330 (7080) b-e	6760 (7570) a-d	6380 (7140)
712 (800)		6500 (7280) a-e	6920 (7750) abc	7120 (7980) a	6850 (7670)
1424 (1600)		6380 (7150) a-e	6470 (7250) a-e	7020 (7860) ab	6620 (7420)
Average		6310 (7060)	6610 (7410)	6890 (7690)	

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.05 probability level by 'F' test.

C.V. = 6.1%

TABLE 31. Effect of Rate and Source of Nitrogen on Corn Grain Yield from Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			lb/ac (kg/ha)		
0 (0)	4230 (4740) c*				
89 (100)	5330 (5970) ab				
178 (200)	5150 (5770) ab	4990 (5590) ab	5160 (5780) ab	5250 (5880) ab	5130 (5750)
356 (400)	4790 (5360) bc	5050 (5660) ab	5050 (5660) ab	5030 (5640) ab	5050 (5650)
712 (800)		5390 (6040) ab	4980 (5570) ab	5180 (5800) ab	5180 (5800)
1424 (1600)		5510 (6170) a	5030 (5630) ab	5260 (5890) ab	5260 (5900)
Average		5240 (5860)	5050 (5660)	5180 (5800)	5160 (5780)

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

C.V. = 6.9%

TABLE 32. Nitrogen Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		% N			
0 (0)	1.68 a*				
89 (100)	1.69 a				
178 (200)	2.11 abc	1.76 a	1.73 a	1.75 a	1.75
356 (400)	2.64 de	2.20 abcd	1.71 a	2.04 ab	1.98
712 (800)		2.50 bcde	2.59 cde	2.58 cde	2.56
1424 (1600)		2.79 e	2.61 cde	2.91 e	2.77
Average		2.31	2.16	2.32	2.26

C.V. = 12%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 33. Nitrogen Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% N				
0	(0)	0.95 d*				
89	(100)	1.17 abc				
178	(200)	1.22 abc	1.22 abc	1.07 cd	1.17 abc	1.15
356	(400)	1.28 a	1.25 ab	1.20 abc	1.13 abc	1.19
712	(800)		1.15 abc	1.12 bc	1.10 bc	1.12
1424	(1600)		1.15 abc	1.25 ab	1.23 ab	1.21
Average			1.19	1.16	1.16	1.17

c.v. = 6.9%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 34. Nitrogen Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		% N			
0 (0)	0.90 d*				
89 (100)	1.32 ab				
178 (200)	1.17 bc	1.08 cd	1.22 abc	1.20 abc	1.17
356 (400)	1.27 abc	1.27 abc	1.23 abc	1.05 cd	1.18
712 (800)		1.23 abc	1.23 abc	1.25 abc	1.24
1424 (1600)		1.20 abc	1.27 abc	1.40 a	1.29
Average		1.20	1.24	1.23	1.22

c.v. = 9.2%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 35. Nutrient Content of Corn Grain, Elora and Cambridge, 1976.

Element	Source of Nitrogen					C.V. %
	Ammonium Nitrate		Calcium Sludge	Alum Sludge	Iron Sludge	
	N rate - lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	
			Elora			
N %	1.93*	1.92	1.92	1.93	1.93	3.5
P %	0.38	0.36	0.31	0.31	0.33	15
K %	0.40	0.37	0.36	0.40	0.34	21
			Cambridge			
N %	1.95	1.97	2.02	2.08	2.02	3.8
P %	0.56	0.60	0.60	0.66	0.54	11
K %	0.54	0.42	0.40	0.50	0.40	20

* None of the values presented in this table for individual elements are significantly different at 0.05 probability by Duncan's Multiple Range Test or by "F" test.

TABLE 36. Nitrate-N Content of First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			$\mu g\ NO_3\text{-}N/g$			
0	(0)	100 a				
89	(100)	100 a				
178	(200)	240 a	170 a	100 a	090 a	120
356	(400)	920 b	150 a	170 a	260 a	190
712	(800)		1110 b	1450 c	1010 b	1190
1424	(1600)		1520 cd	1490 cd	1770 d	1590
Average			740	800	780	770

C.V. = 24.5%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability by "F" test. Sludge source-rate interaction is significant at 0.05 probability.

TABLE 37. Nitrate-N Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg NO_3-N/g			
0 (0)	293 g*				
89 (100)	500 d-g				
178 (200)	583 c-g	470 e-g	573 c-g	417 fg	487
356 (400)	627 b-f	570 c-e	687 a-f	677 a-f	644
712 (800)		783 a-e	593 c-g	890 a-c	755
1424 (1600)		820 a-d	937 ab	990 a	916
Average	650	661	698	743	701

C.V. = 26%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.05 probability level by "F" test.

TABLE 38. Nitrate-N Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		$\mu g\ NO_3$-N/g				
0	(0)	247 f*				
89	(100)	657 cde				
178	(200)	950 bc	437 ef	650 cde	550 def	546
356	(400)	947 bc	583 c-f	1107 ab	813 bcd	834
712	(800)		903 bcd	1167 ab	960 bc	1010
1424	(1600)		950 bc	1180 ab	1457 a	1197
Average			719	1026	925	897

C.V.= 24%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge, and rates of ammonium nitrate are significantly different at 0.05 probability level by "F" test.

TABLE 39. Phosphorus Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source: Ammonium Nitrate	Nitrogen Source: Calcium Sludge	Nitrogen Source: Aluminum Sludge	Nitrogen Source: Iron Sludge	Sludge Average
	% P				
0 (0)	0.24 ab*				
89 (100)	0.24 ab				
178 (200)	0.24 ab	0.27 bc	0.25 ab	0.27 bc	0.26
356 (400)	0.24 ab	0.30 c	0.21 a	0.27 bc	0.26
712 (800)		0.29 c	0.23 ab	0.29 c	0.27
1424 (1600)		0.29 c	0.22 a	0.30 c	0.27
Average		0.29	0.23	0.28	0.27

C.V. = 8.1%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by "F" test.

TABLE 40. Phosphorus Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			% P		
0 (0)	0.11 abc*				
89 (100)	0.11 abc				
178 (200)	0.11 ab	0.11 ab	0.09 bc	0.10 abc	0.10
356 (400)	0.12 a	0.11 ab	0.11 abc	0.09 bc	0.10
712 (800)		0.09 abc	0.08 c	0.09 bc	0.09
1424 (1600)		0.09 abc	0.09 abc	0.10 abc	0.10
Average		0.10	0.09	0.09	0.10

c.v. = 14%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.05 probability level by 'F' test.

TABLE 41. Phosphorus Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			% P		
0 (0)	0.18 a*				
89 (100)	0.13 bc				
178 (200)	0.12 bcd	0.13 bc	0.12 bcd	0.13 bc	0.12
356 (400)	0.12 bcd	0.14 b	0.11 bcd	0.09 d	0.12
712 (800)		0.11 bcd	0.11 cd	0.13 bc	0.11
1424 (1600)		0.11 bcd	0.13 bc	0.13 bc	0.12
Average		0.12	0.12	0.12	0.12

c.v. = 15%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.
Sludge source x rate interaction is significant at 0.05 probability level.

TABLE 42. Sodium Bicarbonate-Extractable Phosphorus in Surface Soil (0-6 in), Bromegrass Experiment. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			μg P/g			
0	(0)	57 fg*				
89	(100)	27 g				
178	(200)	40 fg	90 ef	63 efg	97 def	83
356	(400)	23 g	183 c	73 efg	90 ef	115
712	(800)		367 b	73 efg	120 de	187
1424	(1600)		560 a	97 def	150 cd	269
Average			300	77	114	164

C.V. = 23%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test

Sources and rates of sludge, rates of ammonium nitrate and source x rate interaction are significantly different at 0.01 probability level by "F" test.

TABLE 43. Sodium Bicarbonate-Extractable Phosphorus in Surface Soil (0-6 in), Corn Experiment, Elora. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		µg P/g			
0 (0)	23 f*				
89 (100)	30 f				
178 (200)	30 f	87 c-f	57 ef	53 ef	66
356 (400)	40 ef	87 c-f	80 def	90 c-f	86
712 (800)		210 b	90 c-f	150 bcd	150
1424 (1600		290 a	117 cde	160 bc	189
Average		168	86	113	123

C.V. = 41%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Mutiple Range Test.

Sources and rates of sludge, and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Source x rate interaction is significant at 0.05 probability level.

TABLE 44. Sodium Bicarbonate-Extractable Phosphorus in Surface Soil (0-6 in) Corn Experiment, Cambridge. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg P/g			
0 (0)	103 ef*				
89 (100)	73 f				
178 (200)	73 f	150 de	113 ef	103 ef	122
356 (400)	120 ef	210 c	123 def	110 ef	148
712 (800)		273 b	153 de	170 cd	198
1424 (1600)		397 a	123 def	170 cd	230
Average		258	128	138	175

C.V. = 17%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge, rates of ammoniun nitrate, and source x rate interaction are significantly different at 0.01 probability level by "F" test,

TABLE 45. Potassium Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		% K			
0 (0)	2.40 g*				
89 (100)	2.26 efg				
178 (200)	1.91 abcde	2.32 fg	2.22 defg	2.30 fg	2.28
356 (400)	1.59 a	2.28 fg	1.78 abc	1.85 abcd	1.97
712 (800)		1.70 ab	2.03 bcdefg	2.10 cdefg	1.94
1424 (1600)		1.59 a	1.98 bcdef	2.03 bcdefg	1.87
Average		1.97	2.00	2.07	2.02

C.V. = 9.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge application and source-rate interaction are significantly different at 0.01 probability by "F" test.

TABLE 46. Potassium Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		% K			
0 (0)	0.90 bc*				
89 (100)	0.91 bc				
178 (200)	0.96 bc	0.88 bc	0.86 c	0.84 c	0.86
356 (400)	1.15 abc	0.90 bc	1.04 abc	1.01 bc	0.98
712 (800)		1.16 abc	1.05 abc	1.24 ab	1.15
1424 (1600)		0.97 bc	1.15 abc	1.36 a	1.16
Average		0.98	1.03	1.11	1.04

c.v. = 18%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 47. Effect of Nitrogen Source (Averaged Over Rates) on Ammonium Acetate-Extractable Soil Potassium. Corn, Elora, 1976.

Nitrogen source					
No Nitrogen	Ammonium Nitrate	Calcium Sludge	Alum Sludge	Iron Sludge	Sludge Average
		µg/g			
120	121	124	130	125	126

TABLE 48. Ammonium Acetate-Extractable Potassium in Surface Soil (0-6 in). Bromegrass Experiment, Fall, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg K/g			
0	(0)	135 a*				
89	(100)	101 b				
178	(200)	104 b	117 ab	108 b	117 ab	114
356	(400)	92 b	96 b	92 b	93 b	93
712	(800)		93 b	95 b	97 b	95
1424	(1600)		95 b	107 b	109 b	104
Average			100	100	104	102

C.V. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sludge are significantly different at 0.01 and 0.05 probability levels respectivly by "F" test.

TABLE 49. Ammonium Acetate-Extractable Potassium in Surface Soil (0-6 in). Corn Experiment, Cambridge. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			μg K/g		
0 (0)	129 ab*				
89 (100)	120 ab				
178 (200)	119 ab	100 b	113 ab	139 ab	117
356 (400)	117 ab	108 ab	144 a	120 ab	124
712 (800)		109 ab	120 ab	127 ab	118
1424 (1600)		107 ab	131 ab	124 ab	120
Average		106	127	127	

c.v. = 18%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.05 probability level by 'F' test.

TABLE 50. Calcium Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			% Ca		
0 (0)	0.36 a*				
89 (100)	0.40 ab				
178 (200)	0.45 abc	0.41 ab	0.41 ab	0.45 abc	0.42
356 (400)	0.52 bcd	0.49 bc	0.45 abc	0.44 abc	0.46
712 (800)		0.62 de	0.54 cde	0.56 cde	0.57
1424 (1600)		0.64 e	0.54 cde	0.62 de	0.60
Average		0.54	0.48	0.52	0.51

C.V. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 51. Calcium Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		% Ca			
0 (0)	0.51 de*				
89 (100)	0.65 bcd				
178 (200)	0.65 bcd	0.66 bcd	0.65 bcd	0.54 cde	0.62
356 (400)	0.69 abc	0.62 b-e	0.69 abc	0.49 e	0.60
712 (800)		0.70 ab	0.67 bcd	0.73 ab	0.70
1424 (1600)		0.75 ab	0.83 a	0.71 ab	0.76
Average		0.69	0.71	0.62	0.67

c.v. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by 'F' test. Sources of sludge and rates of ammonium nitrate are significant at 0.05 probability level.

TABLE 52. pH of Surface Soil (0-6 in). Bromegrass Experiment. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
0 (0)	7.17 cd*				
89 (100)	7.03 cd				
178 (200)	7.10 cd	7.40 bc	7.20 cd	7.03 cd	7.21
356 (400)	7.07 cd	7.67 ab	7.23 cd	7.10 cd	7.33
712 (800)		7.90 a	7.17 cd	7.00 d	7.36
1424 (1600)		7.90 a	7.10 cd	6.37 e	7.12
Average		7.72	7.18	6.88	7.26

C.V. = 2.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test

Sources of sludge and source-rate interaction are significantly different at 0.01 probability level by "F" test.

TABLE 53. pH of Surface Soil (0-6 in). Corn Experiment, Elora. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
0 (0)	7.30 de*				
89 (100)	7.63 bc				
178 (200)	7.03 e-g	7.97 a	7.13 d-g	7.40 cd	7.50
356 (400)	7.13 d-g	7.73 ab	7.27 def	7.10 d-g	7.37
712 (800)		7.93 a	7.40 cd	6.97 fg	7.43
1424 (1600)		7.80 ab	7.23 def	6.87 g	7.30
Average		7.86	7.26	7.09	7.40

C.V. = 2.3%

* Individual treatments followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Source x rate interaction is significant at 0.05 probability level.

TABLE 54. pH of Surface Soil (0-6 in). Corn Experiment, Cambridge. Fall, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
0	(0)	7.33 bc *				
89	(100)	7.20 b-e				
178	(200)	7.03 cde	7.77 a	7.20 b-e	7.23 b-e	7.40
356	(400)	7.37 b	7.93 a	7.17 b-e	6.97 e	7.36
712	(800)		7.90 a	7.20 b-e	7.30 bcd	7.47
1424	(1600)		7.90 a	7.13 b-e	7.00 de	7.34
Average			7.88	7.18	7.13	7.39

C.V. = 2.2%

* Individual treatments notfollowed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 55. Magnesium Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			% Mg			
0	(0)					
89	(100)	0.13 a*				
178	(200)	0.13 a	0.13 a	0.13 a	0.14 a	0.13
356	(400)	0.16 abc	0.16 abc	0.14 a	0.15 ab	0.15
712	(800)	0.20 cd	0.18 bc	0.19 bc	0.20 cd	0.19
1424	(1600)		0.20 cd	0.18 bc	0.21 cd	0.20
Average			0.17	0.16	0.18	0.17

C.V. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability by "F" test.

TABLE 56. Magnesium Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	% Mg				
0 (0)	0.21 abc*				
89 (100)	0.25 a				
178 (200)	0.25 a	0.21 abc	0.21 abc	0.20 abc	0.21
356 (400)	0.24 ab	0.22 abc	0.21 abc	0.20 abc	0.21
712 (800)		0.20 abc	0.20 abc	0.18 e	0.19
1424 (1600)		0.19 bc	0.20 abc	0.21 abc	0.20
Average		0.21	0.20	0.20	0.20

c.v. = 12%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 57. Magnesium Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		% Mg			
0 (0)	0.19 e*				
89 (100)	0.26 abc				
178 (200)	0.26 a	0.24 a-d	0.21 a-e	0.20 cde	0.22
356 (400)	0.20 de	0.21 b-e	0.22 a-e	0.20 de	0.21
712 (800)		0.23 a-e	0.22 a-e	0.21 b-e	0.22
1424 (1600)		0.26 ab	0.25 a-d	0.20 cde	0.24
Average		0.24	0.23	0.20	0.22

c.v. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Sources of sludge are significantly different at 0.05 probability level.

TABLE 58. Ammonium Acetate-Extractable Magnesium in Surface Soil (0-6 in). Corn Experiment, Elora. Fall, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		µg Mg/g			
0 (0)	430 abc*				
89 (100)	380 b-e				
178 (200)	480 a	300 ef	450 ab	360 b-e	370
356 (400)	420 abc	320 ef	380 b-e	420 abc	370
712 (800)		290 ef	340 cde	410 a-d	350
1424 (1600)		240 f	320 df	500 a	350
Average		290	380	420	360

c.v. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge, rates of ammonium nitrate and sludge source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 59. Manganese Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Mn/g			
0	(0)	48 f*				
89	(100)	45 ef				
178	(200)	42 def	41 def	36 bcd	38 cde	38
356	(400)	46 f	38 cde	36 bcd	32 abc	35
712	(800)		29 abc	33 abc	32 abc	31
1424	(1600)		28 a	32 abc	43 def	34
Average			34	34	36	35

C.V. = 10%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge, the source-rate interaction and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 60. Manganese Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		µg Mn/g			
0 (0)	34 c*				
89 (100)	45 bc				
178 (200)	49 ab	46 bc	39 bc	36 bc	40
356 (400)	59 a	41 bc	44 bc	41 bc	42
712 (800)		46 bc	43 bc	44 bc	44
1424 (1600)		38 bc	40 bc	38 bc	39
Average		43	42	40	41

c.v. = 16%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 61. Iron Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		µg Fe/g				
0	(0)	33 a-c*				
89	(100)	30 a				
178	(200)	37 a-f	34 a-d	32 ab	42 d-f	36
356	(400)	40 b-f	36 a-e	32 ab	39 b-f	36
712	(800)		43 e-g	44 fg	40 b-f	42
1424	(1600)		52 h	41 c-f	50 gh	48
Average			41	38	43	40

C.V. = 11%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test

Rates of sludge and ammonium nitrate are significanty different at 0.01 probability by "F" test. Source of sludge and source-rate interaction are significant at 0.05 probability level.

TABLE 62. Boron Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		µg B/g				
0	(0)	7.3c*				
89	(100)	7.0bc				
178	(200)	6.3abc	7.0bc	6.7abc	6.7abc	6.8
356	(400)	6.7abc	6.7abc	6.0ab	5.7a	6.1
712	(800)		6.7abc	6.3abc	6.0ab	6.3
1424	(1600)		6.0ab	6.0ab	6.7abc	6.2
Average			6.6	6.3	6.3	6.4

C.V. = 7.9%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.05 probability level by "F" test. Rates of ammonium nitrate are significantly different at 0.01 probability level.

TABLE 63. Cadmium Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate		Nitrogen Source				Sludge Average
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Cd/g				
0	(0)	0.63*				
89	(100)	0.37				
178	(200)	0.37	0.33	0.60	0.40	0.44
356	(400)	0.40	0.40	0.60	0.40	0.47
712	(800)		0.37	0.47	0.47	0.43
1424	(1600)		0.40	0.53	0.67	0.53
Average			0.38	0.55	0.48	0.47

C.V. = 44%

* Individual treatments are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 64. Cadmium Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			μg Cd/g		
0 (0)	0.22 f*				
89 (100)	0.30 def				
178 (200)	0.35 def	0.30 def	0.33 def	0.27 ef	0.30
356 (400)	0.33 def	0.37 def	0.57 abc	0.47 bcd	0.47
712 (800)		0.37 def	0.60 ab	0.67 a	0.54
1424 (1600)		0.43 cde	0.67 a	0.70 a	0.60
Average		0.37	0.54	0.53	0.48

c.v. = 20%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Source x rate of sludge interaction is significant at 0.05 probability level.

TABLE 65. Cadmium Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Cd/g		
0 (0)	0.38 g*				
89 (100)	0.43 fg				
178 (200)	0.50 d-g	0.40 fg	0.53 d-g	0.63 c-g	0.52
356 (400)	0.70 c-g	0.47 efg	0.92 abc	0.51 d-g	0.63
712 (800)		0.53 d-g	0.77 b-e	0.80 bcd	0.70
1424 (1600)		0.63 c-g	1.03 ab	1.13 a	0.93
Average		0.51	0.81	0.77	0.70

c.v. = 25%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range test.

Rates and sources of sludge, and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 66. Metal Content of Corn Grain from Selected Treatments. Elora and Cambridge, 1976.

Element	Source of Nitrogen					C.V. %
	Ammonium Nitrate		Calcium Sludge	Alum Sludge	Iron Sludge	
	N rate - lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	
			Elora			
Cd μg/g	0.09 ab*	0.07 b	0.14 a	0.11 ab	0.12 ab	32
Cr μg/g	0.11 a	0.10 ab	0.11 a	0.07 b	0.11 a	14
Cu μg/g	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	0.0
Ni μg/g	0.10 a	0.08 a	0.05 a	0.10 a	0.10 a	43
Pb μg/g	0.33 a	0.25 a	0.33 a	0.25 a	0.33 a	37
Zn μg/g	21 c	20 c	23 bc	28 a	26 ab	9.9
			Cambridge			
Cd μg/g	0.07 a	0.07 a	0.07 a	0.08 a	0.08 a	32
Cr μg/g	0.11 ab	0.16 a	0.10 ab	0.07 b	0.09 ab	33
Cu μg/g	1.0 b	1.0 b	2.3 a	1.0 b	1.7 ab	29
Ni μg/g	0.08 a	0.12 a	0.15 a	0.15 a	0.20 a	79
Pb μg/g	0.33 a	0.33 a	0.25 a	0.25 a	0.25 a	34
Zn μg/g	35 a	36 a	42 a	48 a	42 a	19

* Individual values for an element not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 67. Cadmium Concentration in First Cut Bromegrass from Selected Treatments from 1973 to 1976 Inclusive.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			μg Cd/g		
1973[§]	0.16 b*	0.17 ab	0.23 ab	0.25 a	0.21 ab
1974[†]	0.05	0.10	0.07	0.10	0.12
1975	0.17 b	0.30 ab	0.30 ab	0.20 ab	0.40 a
1976	0.37 a	0.40 a	0.40 a	0.53 a	0.67 a

* Individual treatments for a given year not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

[§] Data from third cut.

[†] No statistical analysis was possible because a number of samples had less than detection limits of Cd.

TABLE 68. Cadmium Concentration in Corn Stover from Elora and Cambridge from 1973 to 1976 Inclusive.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			μg Cd/g		
			Elora		
1973	0.23 b*	0.28 ab	0.30 ab	0.40 a	0.38 a
1974	0.28 abc	0.31 abc	0.37 abc	0.46 ab	0.54 a
1975	0.24 d	0.43 cd	0.43 cd	0.67 ab	0.80 a
1976	0.30 def	0.33 def	0.43 cde	0.67 a	0.70 a
			Cambridge		
1973	0.38 b	0.58 a	0.60 a	0.39 b†	0.64 a
1974	0.35 c	0.59 bc	0.85 ab	0.43 bc	1.11 a
1975	0.50 bc	0.78 a	0.55 abc	0.46 bc	0.42 bc
1976	0.43 fg	0.70 c-f	0.63 c-g	1.03 ab	1.13 a

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

† No alum sludge was applied at this rate in 1973 because the length of time required to dry the plots would have delayed planting.

TABLE 69. Chromium Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Cr/g			
0	(0)	0.97ab*				
89	(100)	1.10b				
178	(200)	0.87ab	0.93ab	0.93ab	0.90ab	0.92
356	(400)	0.93ab	0.87ab	0.93ab	0.87ab	0.89
712	(800)		0.97ab	0.97ab	1.03ab	0.99
1424	(1600)		0.67a	1.07b	1.10b	0.94
Average			0.86	0.98	0.98	0.94

C.V = 21%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 70. Chromium Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Cr/g		
0 (0)	2.0 b*				
89 (100)	1.6 b				
178 (200)	1.7 b	2.3 b	2.4 b	1.8 b	2.2
356 (400)	1.5 b	1.9 b	3.0 b	1.8 b	2.3
712 (800)		2.0 b	5.0 a	2.1 b	3.0
1424 (1600)		2.9 b	5.4 a	2.1 b	3.5
Average		2.3	4.0	2.0	2.7

c.v. = 37%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Source of sludge is significant at 0.01 probability level by 'F' test. Rates of sludge and ammonium nitrate are significant at 0.05 probability level.

TABLE 71. Copper Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Cu/g			
0	(0)	7.3 a*				
89	(100)	8.0 ab				
178	(200)	8.3 ab	9.7 bcd	8.0 ab	8.3 ab	8.7
356	(400)	8.7 abc	9.0 abc	7.7 ab	9.0 abc	8.6
712	(800)		11.3 de	12.0 ef	10.7 cde	11.3
1424	(1600)		12.0 ef	12.3 ef	13.7 f	12.7
Average			10.5	10.0	10.4	10.3

C.V. = 11.4%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 72. Copper Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			μg Cu/g		
0 (0)	4.3 b*				
89 (100)	5.3 ab				
178 (200)	6.3 a	5.7 ab	6.3 a	6.0 ab	6.0
356 (400)	6.7 a	6.3 a	6.3 a	6.3 a	6.3
712 (800)		5.7 ab	7.0 a	6.3 a	6.3
1424 (1600)		6.3 a	7.0 a	6.7 a	6.7
Average		6.0	6.7	6.3	6.3

c.v. = 15%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 73. Copper Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Cu/g			
0 (0)	5.3 d*				
89 (100)	7.7 bc				
178 (200)	9.3 ab	7.0 cd	8.0 bc	7.7 bc	7.6
356 (400)	8.3 bc	8.0 bc	9.7 ab	7.7 bc	8.4
712 (800)		9.7 ab	8.3 bc	8.0 bc	8.7
1424 (1600)		8.0 bc	9.3 ab	11.0 a	9.4
Average		8.2	8.8	8.6	8.5

c.v. = 14%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Rates of sludge and sludge source x rate interaction are significant at 0.05 probability level.

TABLE 74. Copper Concentration in First Cut Bromegrass from Selected Treatments from 1973 to 1976 Inclusive.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Cu/g		
1973[§]	5.7 c*	10.3 b	16.0 a	11.0 ab	13.0 b
1974	7.7 ef	8.3 c-f	10.0 abc	11.3 a	10.3 ab
1975	8.7 d-h	11.3 bcd	13.3 ab	15.0 a	14.7 a
1976	8.0 ef	8.7 def	12.0 ab	12.3 ab	13.7 a

* Individual treatments for a given year not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

[§] Data from third cut.

TABLE 75. Copper Concentration in Corn Stover from Elora and Cambridge, from 1973 to 1976 Inclusive.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Cu/g		
			Elora		
1973	7.0 a*	5.3 a	8.3 a	9.3 a	10.3 a
1974	6.7 b	9.0 ab	11.3 ab	11.7 ab	11.7 ab
1975	9.7 ab	9.6 ab	8.9 abc	8.5 bc	9.9 ab
1976	5.3 ab	6.7 a	6.3 a	7.0 a	6.7 a
			Cambridge		
1973	10.3 b-f	11.0 a-d	11.7 ab	9.3 def**	12.7 f
1974	8.3 cd	11.0 abc	10.3 a-d	12.0 ab	12.3 a
1975	8.3 ab	8.7 ab	9.3 ab	8.8 ab	8.5 ab
1976	7.7 bc	8.3 bc	8.0 bc	9.3 ab	11.0 a

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

**No alum sludge was applied at this rate in 1973 in Cambridge because the length of time required to dry the plots would have delayed planting.

TABLE 76. Nickel Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		µg Ni/g				
0	(0)	0.50a*				
89	(100)	0.50a				
178	(200)	0.50a	0.50a	0.57a	0.57a	0.54
356	(400)	0.50a	0.50a	0.50a	0.50a	0.50
712	(800)		0.57a	1.50b	0.50a	0.86
1424	(1600)		0.57a	1.10ab	0.53a	0.73
Average			0.53	0.92	0.53	0.66

C.V. = 55%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.05 probability level by "F" test.

TABLE 77. Nickel Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		µg Ni/g			
0 (0)	1.2 bcd*				
89 (100)	0.9 cd				
178 (200)	0.9 cd	1.5 abc	0.8 d	0.9 cd	1.0
356 (400)	0.7 d	1.7 ab	1.0 cd	0.9 cd	1.2
712 (800)		1.6 ab	1.2 bcd	0.8 d	1.2
1424 (1600)		2.0 a	1.2 bcd	0.9 cd	1.4
Average		1.7	1.0	0.9	1.2

c.v. = 29%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Source of sludge is significant at 0.01 probability level by 'F' test. Rate of ammonium nitrate is significant at 0.05 probability level.

TABLE 78. Lead Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg Pb/g			
0	(0)	0.77a*				
89	(100)	0.83ab				
178	(200)	0.80ab	0.80ab	0.77a	1.00ab	0.86
356	(400)	0.90ab	0.73a	0.73a	1.10ab	0.86
712	(800)		0.97ab	1.03ab	0.87ab	0.96
1424	(1600)		1.30b	1.00ab	0.97ab	1.09
Average			0.95	0.88	0.98	0.94

C.V. = 28%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 79. Zinc Concentration in First Cut (June 9), Bromegrass. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			μg Zn/g			
0		16 a*				
89	(100)	15 a				
178	(200)	17 a	20 abc	18 a	24 bcd	20
356	(400)	20 abc	20 abc	19 ab	25 cd	21
712	(800)		28 d	24 bcd	29 d	27
1424	(1600)		25 cd	24 bcd	39 e	29
Average			23	21	29	25

C.V. = 12.8

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Rate-source of sludge interaction is significant at 0.05 probability level.

TABLE 80. Zinc Concentration in Corn Stover at Harvest. Elora, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Zn/g			
0 (0)	20 de*				
89 (100)	15 e				
178 (200)	18 e	30 cd	35 c	30 cd	32
356 (400)	20 de	29 cd	41 bc	38 c	36
712 (800)		64 a	80 a	78 a	74
1424 (1600)		62 ab	69 a	88 a	73
Average		46	56	59	54

c.v. = 28%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Source of sludge is significant at 0.05 probability level.

TABLE 81. Zinc Concentration in Corn Stover at Harvest. Cambridge, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	μg Zn/g				
0 (0)	49 ghi*				
89 (100)	45 hi				
178 (200)	62 d-i	43 i	62 d-i	58 e-i	54
356 (400)	65 d-h	51 f-i	106 abc	69 c-g	75
712 (800)		61 d-i	86 bcd	76 c-f	75
1424 (1600)		76 cde	124 ab	137 a	112
Average		58	95	85	79

c.v. = 23%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 82. Zinc Concentration in First Cut Bromegrass from Selected Treatments from 1973 to 1976 Inclusive

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
	μg Zn/g				
1973[§]	19 c*	26 b	33 a	26 b	31 a
1974	19 f	22 de	28 ab	29 ab	28 ab
1975	17 fg	30 bc	30 bc	33 b	41 a
1976	15 e	20 cde	25 bc	24 bcd	39 a

* Individual treatments for a given year not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

[§] Data from third cut.

TABLE 83. Zinc Concentration in Corn Stover from Elora and Cambridge from 1973 to 1976 Inclusive.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			μg Zn/g		
			Elora		
1973	19 cd*	18 d	30 b-d	37 a-d	41 ab
1974	15 i	22 f-i	36 cde	54 b	89 a
1975	18 e	23 e	55 bc	72 b	106 a
1976	15 e	20 de	62 ab	69 a	88 a
			Cambridge		
1973	64 c	96 bc	137 a	53** c	111 ab
1974	47 fg	80 d-g	151 a	133 abc	135 ab
1975	55 bc	117 abc	124 ab	131 a	77 abc
1976	45 hi	65 d-h	76 cde	124 ab	137 a

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

** No alum sludge was applied at this rate in Cambridge in 1973 because the length of time required to dry the plots would have delayed planting.

TABLE 84. Mercury, Molybdenum and Selenium Contents of Selected Treatments From First Cut Bromegrass (June 9), 1976.

Element	Nitrogen Source					C.V.
	Ammonium nitrate		Lime sludge	Alum sludge	Iron sludge	
	200 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha	(%)
Mo (μg/g)	0.80 a	0.57 a	0.67 a	0.57 a	0.73 a	23
Se (ng/g)	47 ab	65 ab	48 ab	28 b	82 a	38
Hg (ng/g)	21 a*	20 a	21 a	20 a	21 a	12

* Individual values for an element not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range test.

TABLE 85. Molybdenum, Selenium and Mercury Contents of Corn Grain and Stover from Selected Treatments. Elora and Cambridge, 1976.

Element	Source of Nitrogen					C.V. %
	Ammonium Nitrate		Calcium Sludge	Alum Sludge	Iron Sludge	
	N rate - lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	
			Elora - Stover			
Mo µg/g	0.34 b*	0.44 ab	0.62 a	0.50 ab	0.44 ab	24
Se ng/g	50 a	50 a	45 a	50 a	47 a	33
Hg ng/g	17 a	21 a	18 a	18 a	21 a	23
			Cambridge - Stover			
Mo µg/g	0.27 b	0.28 b	0.50 a	0.23 b	0.26 b	30
Se ng/g	57 bc	83 ab	85 a	78 ab	51 c	19
Hg ng/g	23 a	21 a	23 a	21 a	28 a	17
			Elora - Grain			
Mo µg/g	0.44 bc	0.34 c	0.58 a	0.48 ab	0.47 ab	13
Se ng/g	32 a	33 a	22 ab	12 b	28 ab	35
Hg ng/g	3 a	4 a	4 a	4 a	3 a	33
			Cambridge - Grain			
Mo µg/g	0.60 a	0.61 a	0.67 a	0.54 a	0.58 a	28
Se µg/g	0.03 a	0.03 a	0.03 a	0.02 a	0.02 a	74
Hg ng/g	4 a	3 a	4 a	4 a	3 a	44

* Individual values for an element not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 86. Average Concentration of Nutrients and Metals in Corn Stover from Elora and Cambridge which were not Affected by Treatment Effects.

Element	Concentration (± S.D.)
	ELORA
Ca	0.45 ± 0.05%
B	7.3 ± 0.7 μg/g
Cr	1.1 ± 0.2 μg/g
Ni	0.6 ± 0.1 μg/g
Pb	3.1 ± 0.4 μg/g
	Cambridge
K	1.04 ± 0.10%
Mn	60 ± 5 μg/g
B	12 ± 1 μg/g
Pb	8.9 ± 0.9 μg/g

TABLE 87. Aqua Regia-Extractable Soil Phosphorus, Bromegrass Experiment. April, 1976

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil P mg/g					
0-2 (0-5)	0.74 fg*	0.73 fg	3.31 c	5.75 b	7.23 a	5.43
2-4 (5-10)	0.66 gh	0.67 gh	1.61 d	0.89 ef	1.08 e	1.19
4-6 (10-15)	0.66 gh	0.57 h	0.72 g	0.76 fg	0.89 ef	0.79
Average	0.69	0.66	1.88	2.47	3.06	2.47
	Phosphorus applied in sludge (1973-1975) mg/g					
0-6 (0-15)			1.40	1.71	2.15	

* Values followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 88. Aqua Regia-Extractable Soil Calcium, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
			Soil Ca mg/g			
0-2 (0-5)	7.47 fg*	7.70 efg	85.8	16.1 b	9.80 de	37.2
2-4 (5-10)	7.77 efg	9.20 ef	27.7 b	8.47 cd	6.83 g	14.3
4-6 (10-15)	7.67 fg	9.83 de	12.3 d	9.17 cd	7.50 fg	9.65
Average	7.63	8.91	41.9	11.2	8.04	20.4
			Calcium applied in sludge (1973-75) mg/g			
0-6 (0-15)			24.8	2.7	1.9	

* Values followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 89. Aqua Regia-Extractable Soil Aluminum, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4HO_3		Ca-Sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Al mg/g					
0-2 (0-5)	17.5 b*	17.1 b	13.1 c	26.2 a	17.0 b	18.8
2-4 (5-10)	19.2 b	17.2 b	16.5 b	18.7 b	18.2 b	17.8
4-6 (10-15)	17.3 b	18.1 b	18.7 b	18.1 b	18.2 b	18.3
Average	18.0	17.5	16.1	21.0	17.8	18.3
			Aluminum applied in sludge (1973-75) mg/g			
0-6 (0-15)			0.36	2.5	0.70	

* Values followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 90. Aqua Regia-Extractable Soil Iron, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
			Soil Fe mg/g			
0-2 (0-5)	21.3 b*	20.7 b	16.5 c	20.2 b	32.1 a	22.9
2-4 (5-10)	22.3 b	20.7 b	20.3 b	21.2 b	21.8 b	21.1
4-6 (10-15)	21.3 b	21.2 b	21.6 b	20.9 b	21.9 b	21.5
Average	21.6	20.9	19.5	20.8	25.3	21.8
			Iron applied in Sludge, (1973-75) mg/g			
0-6 (0-15)			0.8	0.4	2.4	

* Values followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 91. Aqua Regia-Extractable Soil Manganese, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
			Soil Mn µg/g			
0-2 (0-5)	732 a*	729 a	603 c	669 abc	629 bc	634
2-4 (5-10)	746 a	715 ab	708 ab	744 a	746 a	733
4-6 (10-15)	707 ab	739 a	725 a	716 ab	717 ab	719
Average	728	728	679	710	697	695

* Values followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 92. Aqua Regia-Extractable Soil Cadmium, Bromegrass Experiment. April, 1976

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Cd µg/g					
0-2 (0-5)	0.38 g	0.36 g	1.11 c	1.98 b	5.46 a	2.85
2-4 (5-10)	0.32 g	0.34 g	0.61 de	0.42 fg	0.69 d	0.57
4-6 (10-15)	0.35 g	0.34 g	0.40 fg	0.37 g	0.50 ef	0.42
Average	0.35	0.35	0.71	0.92	2.22	1.28
	Cadmium Applied in Sludge, (1973-75) µg/g					
0-6 (0-15)			0.46	0.42	0.96	

TABLE 93. NTA-Extractable Soil Cadmium, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	µg/g Cd					
0-2 (0-5)	0.24 de	0.23 de	0.47 c	0.96 b	2.36 a	1.26
2-4 (5-10)	0.23 de	0.22 de	0.26 de	0.29 d	0.41 c	0.32
4-6 (10-15)	0.22 e	0.22 e	0.23 de	0.25 de	0.30 d	0.26
Average	0.23	0.22	0.32	0.50	1.02	0.61

TABLE 94. Aqua Regia-Extractable Soil Chromium, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Cr μg/g					
0-2 (0-5)	26 d	25 d	24 d	931 a	129 b	361
2-4 (5-10)	21 d	22 d	24 d	51 c	28 d	34
4-6 (10-15)	22 d	23 d	22 d	44 c	23 d	30
Average	23	23	24	342	60	142
			Chromium Applied in Sludge, (1973-75) μg/g			
0-6 (0-15)			3.5	234	20	

TABLE 95. Aqua Regia-Extractable Soil Copper, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Cu μg/g					
0-2 (0-5)	19 g*	20 fg	89 c	148 b	304 a	184
2-4 (5-10)	23 fg	18 g	37 de	24 fg	39 b	33
4-6 (10-15)	17 g	23 fg	24 fg	23 fg	28 bcd	25
Average	20	20	50	65	123	81
			Copper Applied in Sludge(1973-75) μg/g			
0-6 (0-15)			26	34	66	

* Values followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 96. Aqua Regia-Extractable Soil Lead, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Pb μg/g					
0-2 (0-5)	21 f	22 f	52 c	92 b	360 a	168
2-4 (5-10)	20 f	20 f	28 e	23 ef	41 d	31
4-6 (10-15)	20 f	21 f	23 ef	21 f	28 e	24
Average	20	21	34	46	143	74
			Lead Applied in Sludge (1973-75) μg/g			
0-6 (0-15)			14	18	81	

TABLE 97. Aqua Regia-Extractable Soil Nickel, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen										
	NH_4NO_3				Ca-sludge		Al-sludge		Fe-sludge		Sludge Average
	Nitrogen Rate lb/ac (kg/ha)										
	89 (100)		356 (400)		1424 (1600)		1424 (1600)		1424 (1600)		1424 (1600)
	Soil Ni µg/g										
0-2 (0-5)	14	b*	14	b	11	c	54	a	16	b	27
2-4 (5-10)	14	b	13	b	14	b	16	b	14	b	15
4-6 (10-15)	13	b	14	b	13	b	14	b	13	b	13
Average	14		14		13		28		14		18
	Nickel Applied in Sludge (1973-75) µg/g										
0-6 (0-15)					2.6		12		1.8		

* Values followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 98. NTA-Extractable Soil Nickel, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen										
	NH_4NO_3				Ca-sludge		Al-sludge		Fe-sludge		Sludge Average
	Nitrogen Rate lb/ac (kg/ha)										
	89 (100)		356 (400)		1424 (1600)		1424 (1600)		1424 (1600)		1424 (1600)
	µg/g Ni										
0-2 (0-5)	0.83	def	0.86	d	0.79	def	11.3	a	2.13	b	4.74
2-4 (5-10)	0.63	fg	0.63	fg	0.54	g	1.26	c	0.83	de	0.88
4-6 (10-15)	0.63	fg	0.59	g	0.52	g	0.92	d	0.64	efg	0.69
Average	0.70		0.69		0.62		4.50		1.20		2.10

TABLE 99. Aqua Regia-Extractable Soil Zinc, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Zn µg/g					
0-2 (0-5)	94 e*	96 e	378 b	738 a	681 a	599
2-4 (5-10)	91 e	92 e	177 c	130 d	129 d	145
4-6 (10-15)	90 e	95 e	115 de	114 de	103 de	101
Average	92	94	224	327	306	282
			Zinc Applied in Sludge,(1973-75)µg/g			
0-6 (0-15)			96	165	141	

* Values followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 100. NTA-Extractable Soil Zinc, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	µg/g Zn					
0-2 (0-5)	4.6 f	4.5 f	89 b	230 a	228 a	182
2-4 (5-10)	3.2 f	3.1 f	30 c	13 e	21 cd	21
4-6 (10-15)	3.3 f	4.1 f	15 de	12 e	12 e	13
Average	3.7	3.9	45	85	87	72

TABLE 101. Aqua Regia-Extractable Soil Mercury, Bromegrass Experiment. April, 1976.

Soil Depth in (cm)	Source of Nitrogen					
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Sludge Average
	Nitrogen Rate lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	1424 (1600)
	Soil Hg ng/g					
0-2 (0-5)	39 d*	32 d	260 a	252 a	251 a	254
2-4 (5-10)	33 d	22 d	125 bc	57 d	179 b	120
4-6 (10-15)	26 d	29 d	39 d	26 d	115 c	60
Average	33	28	141	112	181	145
			Mercury Added in Sludge(1973-75,)ng/g			
0-6 (0-15)			250	143	929	

* Values followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 102. Heavy Metals and Nutrients Extracted from 0-6 in (0-15 cm) Soil Depth by Aqua Regia in April, 1976 and Total Amounts Added in Sludge. Corn Experiment, Cambridge.

Element	Source of Nitrogen							
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Ca-sludge	Al-sludge	Fe-sludge
	Nitrogen Rate lb/ac (kg/ha)							
	89(100)	356(400)	1424(1600)	(1424(1600)	1424(1600)	1424(1600)	1424(1600)	1424(1600)
	EXTRACTED					ADDED		
	mg/g soil							
P	0.56c*	0.56c	1.52a	0.97b	1.33a	1.42	1.72	2.22
Ca	4.2 b	4.2 b	24.2 a	5.5 b	6.4 b	32.7	2.8	1.6
Al	8.0 a	8.0 a	9.2 a	8.2 a	8.0 a	0.34	4.94	0.58
Fe	10.7 a	11.1 a	12.2 a	10.4 a	11.9 a	0.79	0.53	2.92
Mn	0.60a	0.57a	0.61a	0.57a	0.55a	0.05	0.01	0.02
	μg/g soil							
Cd	0.51c	0.74abc	0.89ab	0.61bc	1.11a	0.60	0.56	0.96
Cr	12 c	15 c	27 b	144 a	33 b	7	256	48
Cu	22 b	26 b	47 a	28 b	47 a	26	33	64
Ni	7.6 c	8.8 bc	11.3 ab	13.0 a	9.2 bc	4.0	12.8	3.2
Pb	16 d	18 d	29 b	22 c	45 a	19	18	76
Zn	87 b	100 b	182 a	160 a	154 a	108	164	148
	ng/g soil							
Hg	65 c	60 c	174 b	60 c	258 a	240	160	760

*Values for any one element followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 103. Heavy Metals and Nutrients Extracted from 0-6 in (0-15 cm) Soil Depth by Aqua Regia in April, 1976 and Total Amounts Added in Sludge. Corn Experiment, Elora.

Element	Source of Nitrogen NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge	Ca-sludge	Al-sludge	Fe-sludge
	Nitrogen Rate lb/ac (kg/ha)							
	89(100)	356(400)	1424(1600)	1424(1600)	1424(1600)	1424(1600)	1424(1600)	1424(1600)
	EXTRACTED					ADDED		
	mg/g soil							
P	0.68d*	0.67d	1.51c	1.81b	2.05a	1.21	1.73	2.16
Ca	10.4 b	10.5 b	27.7 a	9.9 b	7.8 b	24.6	2.0	1.8
Al	15.2 c	15.9 ab	14.7 c	18.0 a	16.5 ab	0.46	1.80	0.49
Fe	20.2 b	20.4 b	19.8 b	20.6 b	22.9 a	0.94	0.24	2.93
Mn	0.74 a	0.72 a	0.75 a	0.72 a	0.68 a	0.05	0.01	0.02
	µg/g soil							
Cd	0.38d	0.38d	0.56c	0.67b	1.25a	0.28	0.36	1.07
Cr	23 c	31 c	27 c	243 a	39 b	3.5	208	18
Cu	18 e	21 d	35 c	44 b	66 a	20.0	32	64
Ni	14 b	14 b	13 b	25 a	14 a	3.4	10	1.4
Pb	17 c	19 c	27 b	31 b	79 a	15	15	84
Zn	80 d	89 d	147 c	224 a	183 b	96	136	136
	ng/g soil							
Hg	35 c	31 c	37 c	113 b	292 a	200	160	920

*Values for any one element followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 104. NTA-Extractable Metals from 0-6 in (0-15 cm) Soil Depth in Corn Experiments at Cambridge and Elora. April, 1976.

Metal	Source of Nitrogen				
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge
	Nitrogen Rate lb/ac (kg/ha)				
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)
	µg/g soil				
			Cambridge		
Cd	0.40 b*	0.57 b	0.47 b	0.49 b	0.90 a
Ni	0.84 bc	0.87 bc	0.71 c	3.57 a	1.40 b
Zn	20 c	27 c	51 b	78 a	63 ab
			Elora		
Cd	0.24 c	0.27 c	0.30 c	0.43 b	0.90 a
Ni	0.77 bc	0.88 bc	0.61 c	3.42 a	1.14 b
Zn	4.9 c	7.8 c	31.6 b	65.7 a	62.7 a

* Values followed by a common letter for each element are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

5. GREENHOUSE EXPERIMENT

5.1 Objectives

1) To determine the effects of various sewage sludges on crop growth.
2) To determine the effects of metals in sewage sludge on metal uptake by plants.

5.2 Materials and Methods

Nine Ontario sludges were applied to a Grimsby sandy loam soil in plots, and ryegrass was grown. Sludges were supplied at 178, 712 and 1424 lb N/ac (200, 800 and 1600 kg N/ha) per application. A total of five crops of ryegrass were grown and harvested up to March 1976. Sludge was applied before seeding of each crop. The results for these crops were presented in the 1974/75 and 1975/76 reports.

After the fifth crop was harvested, the soils were limed to approximately pH 6.5 if required, and three of the nine sludges were dropped from the experiment. The six sludges retained were chosen because of their high metal content and were added to only half the pots in each treatment before each cropping. To the other half of the pots in each treatment, no further sludge applications were made. Three crops of ryegrass were grown (sixth, seventh and eighth crops). Dates when various operations were performed and rates of fertilizers added are presented in Table 105.

5.3 Results and Discussion

Chemical analyses of sludges applied to the sixth, seventh and eighth crops are presented in Tables 106, 107 and 108. The amounts of nutrients and metals added in the sludges in the sixth, seventh and eighth applications and the total amounts up to the eigth application are presented in Tables 109, 110, 111 and 112. In computing these values, it was assumed that a hectare of soil (15 cm deep) contained 2.24×10^6 kg of soil.

To reduce salinity problems, the pots were leached following the third, fifth and seventh applications of sludge. The concentrations and total amounts of nutrients and metals leached from selected treatments are shown in Tables 113 and 114. An appreciable portion of the potassium, calcium and boron added was removed by leaching (Table 115). Only a small portion of the metals added was removed in the leachates.

Dry matter yields of the sixth, seventh and eighth crops of ryegrass are presented in Tables 116, 117 and 118. In the sixth crop, there were apppreciable differences between treatments continuing to receive sludge and treatments no longer receiving sludge. Yields were higher with the low rate of application where sludge application was continued. Yields of treatments continuing to receive the Fergus sludge at high rates were drastically reduced. Yield reductions with continued use of the Aurora, Sarnia, and North Toronto sludges at high rates were also appreciable. Leaching of the pots prior to growing the seventh crop was particularly beneficial to treatments continuing to receive sludge. Yields across all sludges were higher where sludge was added than in treatments where sludge application had stopped. This was particularly noticeable with the Fergus sludge which had markedly depressed yields when applied at high rates in earlier crops. Due to depletion of soil by repeated sampling the plants were grown in smaller pots for the eighth crop, and average trial yields should therefore not be compared with previous crops. The low light intensity in October and November when this crop was grown is no doubt also a factor affecting yields. Supplemental lighting was provided but is believed to be insufficient when compared with summer conditions.

Continuing high rates of application of the Fergus sludge once again depressed yields in the eighth crop. Treatments receiving sludge at 200 kg N/ha from crops one to five but not thereafter gave the highest yields in the eighth crop following application of supplemental nitrogen. This particular set of treatments had the lowest ryegrass yields in the seventh crop, probably because of insufficient nitrogen following the leaching.

Nitrogen concentration in ryegrass for crops six, seven and eight are presented in Tables 119, 120 and 121. Nitrogen concentration generally increased with rates of sludge application. Sludge applied at the 1600 kg N/ha rate for the first five crops appears to still supply more than adequate nitrogen to the eighth crop. The nitrogen concentration in the crop has dropped where 800 kg N/ha was supplied in sludge for the first five crops.

Phosphorus concentration was quite high in all treatments. Data for crop seven are presented in Table 122. The Midland sludge supplied the most phosphorus, more than three times the amount supplied by the Aurora sludge (Table 110). Plant phosphorus concentration bore no relation to the phosphorus supplied in sludge.

Potassium concentrations in the seventh and eighth crops are presented in Tables 123 and 124 and are quite high, even after leaching in the seventh crop.

Calcium concentrations were relatively high and did not appear to be related to amounts added in sludges (Tables 125 and 126). With few exceptions, sludge treatments reduced plant calcium in comparison with the check treatment.

Magnesium concentrations were quite high, particularly where the Midland sludge continued to be added at high rates (Tables 127 and 128). Leaching prior to growing the seventh crop reduced the magnesium concentrations slightly.

Manganese concentrations were quite high with some treatments receiving the Fergus sludge (Tables 129 and 130). The treatment receiving the Fergus and North Toronto sludges at 1600 kg N/ha at the first application only had higher plant Mn concentration than the treatment that received the sludge at the same rate for every crop (one to eight).

Iron concentrations for the eighth crop are given in Table 131. The concentrations were quite similar to those in the sixth and seventh crops. The treatment receiving the Fergus sludge at 1600 kg N/ha for crops one, six, seven and eight has the lowest Fe/Mn ratio (1:21).

Boron concentrations built up in the ryegrass with repeated applications of sludge, in particular the Midland sludge which supplied the most boron (Tables 132, 133 and 134). The high boron concentrations from the Midland sludge apparently did not affect yields (Table 114). Leaching the pots before growth of the seventh crop of ryegrass greatly reduced the boron concentration, but it built up again in the eighth crop to levels approximately that of the sixth crop.

Cadmium concentrations in the sixth, seventh and eighth crops of ryegrass are presented in Tables 135, 136 and 137. Cadmium concentration in the ryegrass from the check treatment was higher or as high as that from the sludge treatments with the exception of the Guelph and Sarnia sludges. These two sludges supplied much more cadmium than the other sludges. Stoppage of application of the Sarnia sludge to half of the pots after the fifth crop reduced the Cd concentrations in ryegrass in the sixth, seventh and eighth crops. Omission of Guelph sludge in the sixth crop resulted in cadmium concentrations that were higher than in ryegrass that had continued to receive sludge applications. Indeed a similar trend was observed with the Aurora, Fergus and North Toronto sludges, as with the Guelph sludge. Cadmium concentration in ryegrass treated with sludge at 1600 kg N/ha only in the first application was high in relation to the average Cd concentration for treatments with continued application of sludges. The reason for the above observations is not understood but may be associated with the gradual breakdown of components binding Cd in the sludge after a lag period following stoppage of sludge application. The check value for plant Cd appears relatively high, and in comparison, the Midland and Aurora sludges appear to reduce plant Cd. Cadmium concentrations in all eight crops of ryegrass receiving the Guelph and North Toronto sludges are presented in Table 138. There was a tendency for cadmium concentration in the ryegrass to increase slightly from crop to crop, but this tendency was present in the control treatment as well as in those receiving sludge, and hence cannot be attributed to the increasing cadmium content of the soil from crop to crop. There is not a consistent pattern of lower cadmium content in the third, fifth and seventh crops after leaching.

Chromium concentrations in the sixth and eighth crops of ryegrass are presented in Table 139 and 140, and they are relatively low and constant from crop to crop. In the eighth crop, the Aurora and Fergus sludges which supplied the largest amounts of chromium also resulted in the highest chromium concentration in the ryegrass. Although some other treatment effects were significant, the differences were relatively small.

Copper concentration in the ryegrass increased with sludge application rate (Tables 141, 142 and 143). Treatments receiving the

Fergus sludge had very high concentrations of plant copper, particularly where high rates of sludge were applied. The severe depression of yield caused by high rates of the Fergus sludge is believed to be due, in part at least, to copper toxicity. Treatments that did not receive sludge after the fifth crop, tended to produced a slight reduction in plant copper content relative to the treatments receiving sludge. This was most marked in the eighth crop.

Copper concentrations in all eight crops of ryegrass receiving the Sarnia and North Toronto sludges (sludges of moderate copper content) are presented in Table 144. There was a tendency for copper content to be lower in the ryegrass in the first crop after leaching in treatments receiving sewage sludge. There was no apparent increase in copper concentration from crop to crop with sludge application in spite of the increasing copper concentration in the soil.

Nickel concentrations in the sixth, seventh and eighth crops of ryegrass are presented in Tables 145, 146 and 147. They are relatively high in ryegrass that received the Midland and Fergus sludges.

The Midland sludge supplied very large amounts of Ni; the Fergus sludge did not supply appreciably more Ni than the other sludges (Tables 109, 110 and 111) but resulted in much higher Ni concentration in the ryegrass. High nickel concentration, however, did not appear to be toxic to the ryegrass in treatments receiving the Midland sludge, with the possible exception of the eighth crop (Table 118). Treatments that did not receive sludge after the fifth crop tended to have slightly lower plant Ni concentration than treatments that continued to receive sludge.

Nickel concentrations in all eight crops of ryegrass receiving the Midland and North Toronto sludges (the highest and lowest nickel contents of the sludge studied) are presented in Table 148. Leaching of the soil before the third, fifth and seventh crops of ryegrass did not appear to affect the nickel concentration in the ryegrass. Neither was there any tendency for nickel concentration to increase from crop to crop.

Lead concentrations were low and fairly constant from crop to crop (Tables 149 and 150). Omitting sludge application after the fifth crop reduced slightly the Pb concentration in ryegrass.

Zinc concentrations were quite high in ryegrass from treatments receiving the Sarnia, Fergus, Guelph and, to a lesser extent, the North Toronto sludges (Tables 151, 152 and 153). The Sarnia and Fergus sludges supplied large amounts of zinc, with Midland and Guelph supplying considerably less but still appreciably more than North Toronto or Aurora sludges (Tables 109, 110 and 111). Omitting application of sludge after the fifth crop reduced the Zn content in the plants compared to treatments continuing to receive sludges. Zinc concentrations in ryegrass receiving the Fergus sludge were nearly as high as the zinc concentrations in ryegrass receiving the Sarnia sludge, although the Fergus sludge supplied only about half as much zinc. Treatments receiving sludge at 1600 kg N/ha only in the first application had higher Zn concentrations than treatments receiving 200 kg N/ha of sludge per application for eight crops.

Zinc concentrations in all eight crops of ryegrass receiving continued applications of the Sarnia and North Toronto sludges (supplying, respectively, the greatest and a relatively small amount of zinc) are presented in Table 154. The last two leachings of the soil appear to hav resulted in some reduction in zinc concentration in treatments receiving e sludge, but this was not apparent with the first leaching (crop three). There was a tendency for zinc concentration in the ryegrass to increase from the fifth to the eighth crop on treatments receiving sewage sludge.

Mercury concentration was determined in the ryegrass from selected treatments, and sludge application appeared to have little or no effect (Table 155).

Molybdenum concentration was determined in the ryegrass from selected treatments. Sludge application increased Mo concentration in ryegrass (Table 156). The Guelph sludge added the most molybdenum, followed closely by the Midland sludge. Stopping the application of sludge after the fifth crop reduced slightly the Mo concentration in the eighth crop of ryegrass, but not in the sixth or seventh crop.

Selenium concentration was determined in ryegrass from selected treatments (Table 157). The data are too variable to show whether sludge had an effect on Se levels in the ryegrass.

5.4 Summary and Conclusions

Continued application of most sludges reduced yields of ryegrass either through excess salinity, or metal toxicity or both. Leaching prior to cropping reduced these problems, and increased yields. Boron and nickel concentrations were high in ryegrass receiving the Midland sludge, but did not appear to have toxic effects. Omitting the application of sludge after the fifth crop reduced the plant Cd content with two sludges (Midland and Aurora), but generally increased the plant Cd content with the other sludges. Stopping the application of sludge reduced slightly the Cu, Ni, Pb and Zn concentrations in succeeding crops. However, there is evidence that where a high metal sludge had been applied previously at a high rate, the breakdown of sludge constituents after a lag period may release the metal in appreciable amounts. The metal concentrations in ryegrass receiving different sludges did not always correspond to the amount of metal added. The metals in different sludges, therefore, differ in availability because they are in different chemical forms, or because their uptake is influenced by other factors which differ from one sludge to another.

With the possible exception of zinc there was no indication of consistent increase in metal concentration in the ryegrass from one crop to the next even with continued applications of sludge.

TABLE 105. Crop Management Schedule, Greenhouse Experiment, 1976.

Operation	6th Crop	7th Crop	8th Crop
Sludge application completed	April 18	July 2	Sept. 24
Leaching completed		July 13	
Potassium chloride added to all treatments	50 kg K/ha date April 23	100 kg K/ha date July 21	
Potassium chloride added to treatments not receiving sludge			50 kg K/ha date Oct. 7
Ammonium nitrate added to check plots and those receiving only one sludge application.	50 kg N/ha date April 23 date May 3 date May 11 date May 17	50 kg N/ha date July 21 date Aug. 2 date Aug. 9 date Aug. 16	50 kg N/ha date Oct. 7 date Oct. 18 date Oct. 25 date Nov. 2
Ammonium nitrate added to treatment receiving 200 kg N/ha from sludge for first five crops			50 kg N/ha date Oct. 7 date Oct. 18
Ryegrass seeded	April 23	July 21	Oct. 7
Ryegrass harvested	May 28	Aug. 27	Nov. 12

TABLE 106. Chemical Analysis of Sludges Used in Greenhouse for 6th Crop of Ryegrass (Fluid Basis).

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
pH	7.5	7.2	7.4	7.4	7.2	7.7
			mg/ml			
Solids	19	131	118	117	32	70
Total N	0.6	1.3	2.2	3.5	2.0	3.0
Soluble & Exch. NH_4-N	0.05	0.16	0.42	1.24	0.93	0.99
P	0.3	3.0	2.0	3.3	1.3	2.7
K	0.1	0.3	0.5	0.3	0.1	0.3
Ca	1.1	10.9	5.2	7.8	1.6	2.5
Mg	0.1	0.8	1.0	1.1	0.4	0.4
Na	0.33	0.16	0.18	0.20	0.18	0.19
Al	1.50	2.75	0.60	1.00	0.07	0.42
Fe	0.2	2.4	10.0	4.1	2.7	5.3
			µg/ml			
Cu	7	70	58	421	336	112
Zn	12	262	1770	878	672	333
Mn	5	51	484	33	8	32
Cd	0.1	1.6	10.3	24.6	0.3	2.0
Cr	219	177	24	445	126	33
Ni	2	196	4	14	6	2
Pb	7	104	531	187	8	175
Mo	0.5	2.5	3.9	11.4	0.5	2.7
B	0.49	3.01	1.65	2.69	0.77	0.91
Hg	0.03	1.31	0.57	1.83	0.24	1.40
Se	0.036	0.186	<0.001	0.335	<0.001	<0.001

TABLE 107. Chemical Analysis of Sludges used in Greenhouse for 7th Crop of Ryegrass (Fluid Basis).

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
pH	7.4	7.4	7.4	7.6	6.4	7.4
			mg/ml			
Solids	20	108	48	38	70	66
Total N	0.60	0.85	1.10	1.14	2.25	2.55
Soluble & Exch. NH_4-N	0.12	0.17	0.46	0.49	0.81	0.98
P	0.40	1.95	0.80	1.30	1.90	2.00
K	0.06	0.06	0.12	0.09	0.11	0.21
Ca	0.8	17.5	1.9	2.5	3.5	2.5
Mg	0.09	1.51	0.42	0.29	0.72	0.42
Na	0.27	0.22	0.14	0.21	0.37	0.25
Al	1.86	0.82	0.33	1.57	0.27	0.70
Fe	0.17	0.92	3.48	1.05	3.33	4.40
			µg/ml			
Cu	17	36	31	87	910	87
Zn	22	159	678	192	1367	199
Mn	5.0	27.0	64.5	11.5	15.5	26.5
Cd	0.05	0.48	5.95	3.35	0.49	1.39
Cr	270	75	11	69	394	38
Ni	5	229	1	3	15	2
Pb	8	38	198	61	15	121
Mo	0.55	1.67	2.22	2.22	1.67	2.77
B	0.45	2.48	1.05	0.92	1.54	1.20
Hg	0.06	1.20	0.43	0.41	0.32	1.43
Se	0.05	0.10	<0.001	0.15	0.09	<0.001

TABLE 108. Chemical Analysis of Sludges used in Greenhouse for 8th Crop of Ryegrass (Fluid Basis).

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
pH	8.1	8.4	8.2	7.6	8.0	7.5
			mg/ml			
Solids	19	150	63	54	56	65
Total N	0.2	1.1	1.2	1.6	2.4	2.9
Soluble & Exch. NH_4-N	0.01	0.07	0.14	0.26	1.00	0.90
P	0.3	3.2	1.5	2.2	1.8	3.1
K	0.1	0.1	0.2	0.2	0.2	0.3
Ca	0.6	27.4	2.2	3.6	3.2	2.7
Mg	0.1	1.7	0.6	0.3	0.6	0.4
Na	0.35	0.23	0.13	0.19	0.37	0.17
Al	2.70	0.86	0.31	2.16	0.16	0.72
Fe	0.21	1.50	5.64	1.62	2.97	5.06
			µg/ml			
Cu	14	62	39	164	952	104
Zn	25	263	972	288	1344	222
Mn	5	41	207	18	15	32
Cd	0.06	0.67	8.15	5.12	0.42	1.69
Cr	261	74	13	100	336	32
Ni	5	331	3	5	15	2
Pb	9	61	276	92	14	124
Mo	0.38	1.88	2.35	2.02	0.56	2.61
B	0.35	3.45	1.38	1.02	1.34	1.11
Hg	0.52	1.13	0.35	0.38	0.26	1.31
Se	0.045	0.15	<0.001	0.224	0.034	<0.001

TABLE 109. Total Amounts of Nutrients and Metals Added in 6th Application of Sludge at 200 kg N/ha to Greenhouse Experiment.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	6333	20153	10727	6685	3200	4667
Total N	200	200	200	200	200	200
Soluble & Exch. NH_4-N	17	25	38	71	93	66
P	100	461	180	189	130	180
K	33	46	45	17	10	20
Ca	367	1677	473	446	160	167
Mg	33	123	91	63	40	27
Na	110	25	16	11	18	13
Al	500	423	55	57	7	28
Fe	68	369	909	234	270	353
Cu	2.3	10.8	5.3	24.1	33.6	7.5
Zn	4	40	161	50	67	22
Mn	1.7	7.9	43.9	1.9	0.8	2.1
Cd	0.03	0.25	0.94	1.41	0.03	0.13
Cr	72.9	27.2	2.2	25.4	12.6	2.2
Ni	0.7	30.2	0.4	0.8	0.1	0.1
Pb	2.3	16.0	48.3	10.7	0.8	11.7
Mo	0.17	0.38	0.35	0.65	0.05	0.18
B	0.16	0.47	0.15	0.15	0.08	0.06
Hg	0.01	0.20	0.05	0.10	0.03	0.09
Se	0.01	0.03	<0.0001	0.02	<0.0001	<0.0001

TABLE 110. Total Amounts of Nutrients and Metals Added in 7th Application of Sludge at 200 kg N/ha to Greenhouse Experiment.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	6666	25411	8727	6666	6222	5176
Total N	200	200	200	200	200	200
Soluble & Exch. NH_4-N	40	40	83	86	72	77
P	133	459	145	228	167	157
K	20	14	22	16	10	17
Ca	267	4118	345	439	311	195
Mg	30	355	76	51	64	33
Na	90	52	25	37	33	20
Al	620	193	60	275	24	55
Fe	57	216	633	184	296	345
Cu	6	9	6	15	81	7
Zn	7	37	123	34	122	16
Mn	1.7	6.4	11.8	2.0	1.4	2.1
Cd	0.02	0.11	1.08	0.59	0.04	0.11
Cr	90	18	2	12	35.0	3
Ni	1.7	54.0	0.2	0.5	1.3	0.2
Pb	2.7	8.9	36.0	10.7	1.3	9.5
Mo	0.18	0.39	0.40	0.39	0.15	0.22
B	0.15	0.58	0.19	0.61	0.14	0.09
Hg	0.02	0.28	0.08	0.07	0.03	0.11
Se	0.017	0.023	<0.0002	0.026	0.008	<0.0001

TABLE 111. Total Amounts of Nutrients and Metals Added in 8th Application of Sludge at 200 kg N/ha to Greenhouse Experiment.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	19000	27272	10500	6750	4666	4482
Total N	200	200	200	200	200	200
Soluble & Exch. NH_4-N	10	13	23	33	83	62
P	300	581	250	275	150	214
K	100	18	33	25	17	21
Ca	600	4982	367	450	267	186
Mg	100	309	100	38	50	28
Na	350	42	22	24	31	12
Al	2700	156	52	270	13	50
Fe	210	272	340	202	247	349
Cu	1.4	11.3	6.5	20.5	79.0	7.2
Zn	3	48	162	36	112	15
Mn	0.5	7.5	34.5	2.3	1.3	2.2
Cd	0.01	0.13	1.36	0.64	0.04	0.12
Cr	26.0	13.5	2.2	12.5	27.9	2.2
Ni	0.5	60.2	0.5	0.6	1.3	0.2
Pb	0.9	11.1	46.0	11.5	1.2	8.6
Mo	0.04	0.34	0.39	0.25	0.05	0.18
B	0.04	0.63	0.23	0.13	0.11	0.08
Hg	0.05	0.21	0.06	0.05	0.02	0.09
Se	0.01	0.03	<0.0001	0.03	0.01	<0.0001

TABLE 112. Total Amounts of Nutrients and Metals Added to Soil in Greenhouse Experiment in Eight Crops in Sludge at 200 kg N/ha per Application.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
	kg/ha					
Solids	55,100	153,500	66,700	45,100	31,600	35,800
Total N	1,600	1,600	1,600	1,600	1,600	1,600
Soluble & Exch. NH_4-N	368	254	484	589	710	543
P	1,090	4,020	1,510	1,950	931	1,500
K	219	197	264	135	98	135
Ca	2,770	28,400	2,850	2,730	1,760	1,450
Mg	325	1,530	690	390	390	230
Na	640	260	114	200	293	99
Al	5,640	1,660	376	1,075	107	381
Fe	500	1,540	4,600	1,235	1,640	2,630
Cu	21	63	48	131	282	51
Zn	36	223	846	273	516	113
Mn	11	45	169	12	8	15
Cd	0.21	0.91	6.4	9.0	0.60	1.04
Cr	377	117	11	131	121	20
Ni	7.3	354	2.3	4.2	5.7	1.2
Pb	13	87	256	64	11.0	70
Mo	0.64	1.92	1.65	3.0	0.40	1.12
B	2.7	6.1	1.7	1.9	1.1	0.9
Hg	0.13	1.2	0.39	0.42	0.13	0.70
Se	0.84	0.58	<0.002	1.18	0.026	0.010

TABLE 113. Concentration of Nutrients and Heavy Metals in Leachate from Selected Treatments before 7th Crop of Ryegrass

Sludge	Rate (kg N/ha)	NH_4-N	NO_3-N	P	K	Ca	Mg	Fe	Mn
				mg/l					
Aurora	1600	6.0	248	0.38	35	440	49	0.025	0.45
Midland	1600	1.5	60	0.94	6.5	103	43	0.05	<0.01
Sarnia	1600	6.3	233	0.45	14	392	89	0.015	3.0
Guelph	200	3.5	30	1.25	5.2	128	24	0.02	0.30
	800	4.7	93	0.68	7.8	201	38	0.02	0.42
	1600	4.8	175	0.63	17	417	73	0.27	1.13
	1600*	33	118	0.91	19	260	41	0.06	1.53
Fergus	200	3.3	16	1.45	3.5	95	14	<0.01	0.15
	800	35	150	1.48	19	271	43	0.23	1.86
	1600	42	165	1.71	36	333	55	0.21	7.79
	1600*	62	255	1.43	32	392	69	0.16	14.2
N. Toronto	200	4.1	20	1.52	4.2	96	12	0.01	0.21
	800	24	183	1.50	14	297	55	0.015	2.95
	1600	24	150	1.98	18	280	57	0.10	5.10
	1600*	62	248	1.13	22	392	60	0.13	13.3

* Sludge applied once to first crop, but not to crops 2,3,4 and 5

† Leached after addition of sludge before growing the 7th crop.

TABLE 113 (Cont'd)

Sludge	Rate	Cu	Zn	Cd	Cr	Ni	Pb	B
				µg/l				
Aurora	1600	171	73	3.8	17.8	65	12.5	520
Midland	1600	161	39	<1	3.2	460	5.3	420
Sarnia	1600	160	2479	24	8.3	35	7.3	310
Guelph	200	232	75	8.8	6.3	35	5.3	146
	800	257	119	16.3	6.5	45	10.0	125
	1600	426	292	49	10.4	70	23	270
	1600*	402	115	17.5	10.4	70	12.5	250
Fergus	200	192	64	1.7	6.3	20	5.1	<40
	800	867	1475	6.1	9.4	105	8.3	270
	1600	2980	4302	11.3	14.6	245	10.4	420
	1600*	1854	3302	21.5	13.6	175	15.6	210
N. Toronto	200	76	33	1.4	4.2	10	5.3	40
	800	171	354	7.9	7.3	40	6.3	167
	1600	315	721	11.3	7.3	60	10.4	313
	1600*	183	560	18.3	25.0	60	12.5	125

TABLE 114. Total Amounts of Nutrients and Heavy Metals Leached from Selected Treatments before 7th Crop of Ryegrass

Sludge	Rate kg N/ha	NO_3-N	NH_4-N	K	P	Mg	Fe	Ca	B
				kg /ha					
Aurora	1600	557	13	80	0.84	109	.06	991	1.17
Midland	1600	126	3	14	2.07	101	.10	216	0.92
Sarnia	1600	545	15	34	1.06	213	.05	935	0.73
Guelph	200	71	8	12	2.97	56	.05	304	0.35
	800	244	13	20	1.79	99	.04	528	0.33
	1600	484	13	47	1.74	200	.77	1153	0.75
	1600*	329	91	54	2.58	114	.17	728	0.70
Fergus	200	38	8	8	3.47	34	.02	231	0.10
	800	374	86	49	3.70	108	.31	672	0.67
	1600	378	95	81	3.92	127	.47	762	0.96
	1600*	774	151	78	3.36	170	.39	958	0.52
North Toronto	200	45	1	10	3.64	29	.02	230	0.10
	800	447	60	30	3.70	133	.04	728	0.41
	1600	389	63	47	5.15	148	.25	728	0.81
	1600*	570	142	51	2.58	138	.30	90	0.29

TABLE 114. (Cont'd)

Sludge	Rate kg N/ha	Mn	Cu	Zn	Ni	Cd	Cr	Pb
		kg/ha				g/ha		
Aurora	1600	1.01	0.39	0.16	0.15	8	40	28
Midland	1600	0.02	0.34	0.08	0.98	2	7	117
Sarnia	1600	7.05	0.38	5.82	0.08	56	20	17
Guelph	200	0.70	0.55	0.18	0.08	21	15	12
	800	1.10	0.67	0.31	0.12	43	17	26
	1600	3.13	1.18	0.81	0.19	136	29	64
	1600*	4.28	1.13	0.32	0.20	49	29	35
Fergus	200	0.35	0.46	0.15	0.05	4	15	12
	800	4.63	2.16	3.67	0.25	15	24	19
	1600	17.81	6.83	9.86	0.56	26	33	29
	1600*	34.66	4.54	8.06	0.43	52	33	38
North Toronto	200	0.50	0.18	0.08	0.02	3	10	12
	800	7.22	0.42	0.87	0.10	20	18	16
	1600	13.27	0.82	1.86	0.16	29	19	27
	1600*	30.41	0.42	1.29	0.14	42	57	29

* Sludge applied once to first crop, but not to crops 2, 3, 4 and 5.

TABLE 115. Total Amount of Nutrients and Heavy Metals Leached from Selected Treatments before 7th Crop of Ryegrass, Expressed as Percentage of Amount Added in 7th Application.

Sludge	N-rate (kg N/ha)	(NO_3+NH_4)-N	K	P	Mg	Fe	Ca	B
Aurora	1600	35.6	50	0.08	45	.01	46	130
Midland	1600	8.1	19	0.06	3.6	.005	0.67	20
Sarnia	1600	35.0	19	0.09	35	.001	33.8	48
Guelph	200	39.5	75	1.30	109	.027	69	57
	800	32.1	31	0.19	48	.005	30	13.5
	1600	31.0	37	0.09	49	.05	33	15.3
	1600*	26.3	42	0.14	28	.01	21	14.3
Fergus	200	23.0	80	2.08	53	.007	74	71
	800	57.5	122	0.55	42	.026	54	120
	1600	29.5	101	0.29	45	.020	46	85
	1600*	57.8	98	0.25	33	.016	38	46
N. Toronto	200	23.0	59	2.32	87	.005	118	111
	800	63.4	44	0.59	100	.003	93	113
	1600	28.3	35	0.41	56	.009	47	112
	1600*	44.5	37	0.21	52	.01	6	40

*Sludge applied once to first crop, but not to crops 2, 3, 4 and 5.

TABLE 115. (Cont'd)

Sludge	N-rate (kg N/ha)	Mn	Cu	Zn	Ni	Cd	Cr	Pb
Aurora	1600	7.3	0.81	0.29	0.11	5	0.005	0.13
Midland	1600	0.04	0.50	0.03	0.23	0.20	0.005	0.16
Sarnia	1600	7.5	0.80	0.59	5.0	0.60	0.125	0.006
Guelph	200	35	3.7	0.53	2.0	3.5	0.125	0.11
	800	14	1.1	0.23	6.0	1.8	0.04	0.06
	1600	20	0.98	0.29	4.8	2.9	0.03	0.07
	1600*	27	0.94	0.12	5.0	1.04	0.03	0.04
Fergus	200	25	0.56	0.12	3.8	10.0	0.04	0.9
	800	83	0.61	0.75	4.8	9.3	0.02	0.37
	1600	16	0.40	1.01	5.4	8.1	0.01	0.28
	1600*	31	0.60	0.83	4.1	16.3	0.01	0.36
N. Toronto	200	23	2.6	0.50	10	2.7	0.33	0.13
	800	86	1.5	1.40	12.5	4.5	0.15	0.04
	1600	79	1.5	1.45	10.0	3.3	0.08	0.04
	1600*	181	0.80	1.00	8.8	4.8	0.24	0.04

*Sludge applied once to first crop, but not to crops 2, 3, 4 and 5.

TABLE 116. Dry Matter Yield of 6th Crop of Ryegrass After Addition of Sewage Sludge Before Each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	D.M. g/pot										
None											4.39
Aurora	3.40	3.38	3.67	4.41	3.71	4.17	3.47	2.27	2.12	3.01	3.36
Midland	3.19	2.92	2.76	3.98	3.21	2.74	3.00	4.19	3.40	3.33	3.27
Sarnia	3.11	3.51	3.41	4.45	3.61	4.62	3.61	2.78	4.21	3.81	3.71
Guelph	2.77	3.12	2.93	3.55	3.09	3.52	4.08	3.24	3.74	3.64	3.37
Fergus	3.68	4.72	2.55	5.05	4.00	4.86	3.04	0.24	1.10	2.31	3.16
N. Toronto	3.57	3.56	4.37	5.32	4.21	4.25	5.03	3.08	3.00	3.84	4.02
Mean	3.29	3.54	3.28	4.46	3.64	4.03	3.71	2.63	2.93	3.32	3.48

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - N.S.
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 117. Dry Matter Yield of 7th Crop of Ryegrass After Addition of Sewage Sludge Before Earch of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 5th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	D.M. G/Pot										
None											5.45
Aurora	1.55	3.25	4.55	4.60	3.49	3.40	5.35	6.35	6.75	5.46	4.48
Midland	2.85	4.05	4.65	4.35	3.98	2.35	4.25	6.85	5.50	4.74	4.36
Sarnia	1.95	3.45	4.00	5.35	3.69	2.95	5.10	7.15	4.30	4.88	4.28
Guelph	1.90	2.95	4.20	4.00	3.26	2.90	3.35	5.00	6.45	4.43	3.84
Fergus	1.95	3.35	3.45	4.85	3.40	2.55	4.40	4.50	4.50	3.99	3.69
N. Toronto	1.70	3.10	3.80	3.65	3.06	2.25	4.30	5.95	4.40	4.23	3.64
Mean	1.98	3.36	4.11	4.47	3.48	2.73	4.46	5.97	5.32	4.62	4.05

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	-.01
Sludge addition	- .01	Addition x rate	-.01

TABLE 118. Dry Matter Yield of 8th Crop of Ryegrass After Addition of Sewage Sludge Before Each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	D.M. g/pot										
None											2.45
Aurora	3.35	1.85	2.10	2.50	2.45	2.30	2.45	2.10	2.85	2.43	2.44
Midland	2.75	1.85	2.70	2.15	2.36	2.25	2.60	2.35	2.70	2.48	2.42
Sarnia	3.15	1.55	1.90	2.35	2.24	2.25	2.50	2.35	3.05	2.54	2.39
Guelph	3.10	1.25	2.15	1.50	2.00	2.45	2.85	2.70	2.40	2.60	2.30
Fergus	2.90	0.95	2.05	1.55	1.86	2.85	1.10	0.30	0.35	1.15	1.51
N. Toronto	3.05	2.30	1.75	2.05	2.29	2.45	3.10	2.70	3.55	2.95	2.62
Mean	3.05	1.63	2.11	2.02	2.20	2.43	2.43	2.08	2.48	2.36	2.28

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .05

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 119. Nitrogen Concentration in 6th Crop of Ryegrass After Addition of Sewage Sludge Before Each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					N %						
None											4.84
Aurora	2.89	4.24	4.30	5.43	4.21	3.75	4.47	5.34	5.17	4.68	4.45
Midland	3.67	4.66	5.49	5.51	4.83	2.51	5.21	5.20	4.25	4.37	4.60
Sarnia	2.12	3.96	4.32	5.22	3.90	3.27	5.22	5.34	5.32	4.78	4.34
Guelph	3.03	3.41	4.40	5.41	4.06	3.70	5.01	5.33	5.33	4.84	4.45
Fergus	2.97	4.73	4.03	5.28	4.25	4.56	5.28	4.99	4.63	4.86	4.56
N. Toronto	3.25	4.63	4.58	4.93	4.34	4.72	4.88	4.66	5.46	4.93	4.64
Mean	2.99	4.27	4.52	5.30	4.27	3.75	5.06	5.14	5.02	4.74	4.51

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - N.S.
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 120. Nitrogen Concentration in 7th Crop of Ryegrass After Addition of Sewage Sludge Before Each of the First Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					N%						
None											5.45
Aurora	2.08	3.85	4.80	6.08	4.20	3.15	5.58	5.83	5.55	5.03	4.61
Midland	2.40	2.45	5.80	6.10	4.69	3.20	5.03	5.60	6.20	5.01	4.85
Sarnia	1.88	3.25	5.35	5.75	4.06	2.85	3.35	4.93	5.93	4.26	4.16
Guelph	2.03	2.60	4.95	5.83	3.85	3.28	3.35	5.70	5.40	4.43	4.14
Fergus	2.15	2.85	5.63	5.55	4.04	3.63	4.90	4.43	4.90	4.46	4.25
N. Toronto	2.10	4.10	3.50	6.13	3.96	3.05	4.08	3.50	4.93	3.89	3.92
Mean	2.10	3.52	5.00	5.90	4.13	3.19	4.38	5.00	5.48	4.51	4.32

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 121. Nitrogen Concentration in 8th Crop of Ryegrass After Addition of Sewage Sludge Before Each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	N %										
None											5.35
Aurora	4.05	2.40	3.65	5.23	3.83	4.05	5.05	5.18	5.08	4.84	4.33
Midland	4.18	3.80	4.73	5.30	4.50	4.05	5.05	5.40	6.15	5.16	4.83
Sarnia	4.28	2.88	4.65	5.05	4.21	3.48	4.40	5.58	4.98	4.61	4.41
Guelph	4.10	2.73	3.58	5.55	3.99	4.60	4.80	4.73	5.35	4.87	4.43
Fergus	4.35	1.95	5.20	4.40	3.98	4.73	5.65	5.55	5.18	5.28	4.63
N. Toronto	4.38	2.33	2.95	5.23	3.72	4.98	5.08	5.38	5.43	5.21	4.47
Mean	4.22	2.68	4.13	5.13	4.04	4.31	5.00	5.30	5.36	4.99	4.52

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 122. Phosphorus Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

Sludge	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					P%						
None											0.53
Aurora	0.57	0.58	0.43	0.49	0.52	0.65	0.46	0.43	0.42	0.49	0.50
Midland	0.60	0.53	0.51	0.63	0.57	0.64	0.53	0.49	0.54	0.55	0.56
Sarnia	0.62	0.70	0.63	0.57	0.63	0.67	0.65	0.53	0.71	0.64	0.63
Guelph	0.60	0.78	0.68	0.62	0.67	0.74	0.76	0.62	0.63	0.68	0.68
Fergus	0.58	0.76	0.72	0.52	0.64	0.70	0.71	0.75	0.72	0.72	0.68
N. Toronto	0.62	0.81	0.78	0.57	0.69	0.73	0.81	0.90	0.87	0.82	0.76
Mean	0.60	0.69	0.62	0.56	0.62	0.69	0.65	0.62	0.65	0.65	0.63

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01
Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 123. Potassium Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					K%						
None											3.09
Aurora	3.73	3.73	3.70	3.88	3.76	3.70	3.55	4.57	3.87	3.92	3.84
Midland	3.76	3.63	4.11	3.56	3.76	4.13	3.61	3.61	3.51	3.71	3.74
Sarnia	3.90	3.91	3.55	3.27	3.65	3.76	3.94	3.66	4.88	4.06	3.86
Guelph	3.67	4.18	4.02	3.88	3.93	3.92	4.32	4.28	3.43	3.98	3.96
Fergus	3.59	4.16	5.18	3.75	4.17	3.84	3.92	4.93	3.73	4.10	4.13
N. Toronto	4.13	3.99	3.58	3.52	3.81	3.93	3.45	3.71	4.07	3.79	3.80
Mean	3.80	3.93	4.02	3.64	3.64	3.85	3.80	4.13	3.91	3.93	3.89

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	- N.S.
Sludge additon	- N.S.	Addition x rate	- N.S.
		Source x rate x addition	- .01

TABLE 124. Potassium Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	K %										
None											3.54
Aurora	4.05	4.55	4.18	4.39	4.29	3.99	5.14	6.23	5.71	5.27	4.78
Midland	4.30	4.41	4.34	4.57	4.40	3.34	3.28	4.57	4.49	3.92	4.16
Sarnia	5.05	4.95	4.52	3.98	4.62	4.77	4.12	5.60	4.72	4.80	4.71
Guelph	4.69	5.18	5.00	4.77	4.91	3.44	3.77	5.05	4.59	4.21	4.56
Fergus	4.57	4.75	5.85	4.49	4.91	2.76	4.91	3.91	3.64	3.80	4.36
N. Toronto	4.60	4.24	5.31	3.96	4.53	3.81	3.12	4.26	3.92	3.78	4.15
Mean	4.54	4.68	4.86	4.36	4.61	3.68	4.06	4.93	4.51	4.29	4.45

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 125. Calcium Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Ca%						
None											1.46
Aurora	1.02	1.06	1.09	1.32	1.12	1.00	1.04	1.06	0.91	1.00	1.06
Midland	1.16	1.14	0.96	1.39	1.16	1.20	0.95	0.72	0.87	0.93	1.04
Sarnia	0.93	1.01	1.14	1.28	1.09	0.94	0.85	1.16	1.35	1.07	1.08
Guelph	0.89	0.90	0.91	1.50	1.05	1.14	1.13	1.13	1.38	1.19	1.12
Fergus	1.10	0.94	1.23	1.17	1.11	1.28	1.23	1.09	0.97	1.14	1.12
N. Toronto	1.03	1.22	1.21	1.69	1.28	1.11	1.08	0.89	1.17	1.06	1.17
Mean	1.02	1.04	1.09	1.39	1.13	1.11	1.04	1.01	1.10	1.07	1.10

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .05
Sludge rate - .01
Sludge addition- .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - N.S.

TABLE 126. Calcium Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Ca %						
None											1.76
Aurora	0.93	1.07	1.09	1.35	1.11	0.99	0.99	1.08	1.24	1.07	1.09
Midland	1.04	1.00	0.81	1.65	1.12	1.17	0.84	0.80	1.01	0.95	1.04
Sarnia	0.96	0.86	1.21	1.45	1.12	0.98	1.16	1.15	1.04	1.08	1.10
Guelph	0.89	1.03	1.03	1.50	1.11	1.08	1.20	1.02	1.16	1.12	1.11
Fergus	1.03	1.00	1.40	1.51	1.23	1.14	1.69	1.57	1.72	1.53	1.38
N. Toronto	1.04	1.00	1.14	1.82	1.25	1.18	1.26	1.10	1.18	1.18	1.21
Mean	0.98	0.99	1.11	1.54	1.16	1.09	1.19	1.12	1.22	1.15	1.16

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - N.S.

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 127. Magnesium Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Mg %										
None											.38
Aurora	.32	.35	.39	.48	.38	.33	.36	.42	.35	.36	.37
Midland	.27	.40	.60	.45	.43	.33	.48	.63	.60	.51	.47
Sarnia	.31	.40	.50	.46	.42	.33	.31	.44	.51	.40	.41
Guelph	.35	.37	.44	.47	.41	.31	.32	.46	.38	.37	.39
Fergus	.34	.36	.50	.43	.40	.39	.39	.33	.39	.37	.39
N. Toronto	.35	.43	.41	.45	.41	.33	.36	.34	.41	.36	.38
Mean	.32	.38	.47	.46	.41	.34	.37	.43	.44	.39	.40

*Sludge was added before the first crop but not before crops 2,3,4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Source	Significance	Source	Significance
Sludge source	.01	Source x rate	.01
Sludge rate	.01	Source x addition	.01
Sludge addition	.05	Addition x rate	N.S.
		Source x rate x addition	.01

TABLE 128. Magnesium Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Mg %										
None											.42
Aurora	.39	.33	.39	.47	.39	.37	.48	.51	.45	.45	.42
Midland	.39	.47	.56	.46	.47	.45	.66	.89	.97	.74	.60
Sarnia	.47	.39	.66	.60	.53	.40	.52	.71	.58	.55	.54
Guelph	.48	.40	.49	.49	.46	.45	.50	.49	.55	.49	.48
Fergus	.47	.37	.67	.50	.50	.54	.66	.55	.54	.57	.54
N. Toronto	.46	.37	.44	.47	.43	.53	.61	.59	.58	.57	.50
Mean	.44	.39	.53	.50	.46	.45	.57	.62	.61	.56	.51

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 129. Manganese Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Mn µg/g						
None											106
Aurora	94	62	71	108	83	38	26	202	36	75	79
Midland	65	99	72	97	83	74	109	62	140	96	90
Sarnia	64	16	22	36	34	35	16	172	33	63	49
Guelph	80	15	20	96	53	27	17	35	29	27	40
Fergus	71	21	54	182	82	40	16	115	147	79	80
N. Toronto	103	36	27	153	80	52	32	82	205	93	86
Mean	79	42	44	112	69	44	36	111	98	72	71

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - N.S.

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 130. Manganese Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Mn µg/g										
None											125
Aurora	89	93	82	154	105	61	88	242	169	140	122
Midland	47	117	70	173	102	51	120	46	75	73	87
Sarnia	83	20	28	44	44	58	18	89	27	48	46
Guelph	76	22	20	86	51	28	19	26	46	30	40
Fergus	111	31	35	375	138	55	33	196	627	227	183
N. Toronto	132	29	29	168	89	77	47	79	223	106	98
Mean	90	52	44	167	88	55	54	113	194	104	96

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 131. Iron Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Fe µg/g										
None											103
Aurora	89	78	75	94	84	68	89	70	73	75	79
Midland	88	69	70	85	78	58	65	59	73	63	71
Sarnia	80	70	63	88	75	88	68	80	70	76	76
Guelph	75	71	65	104	79	80	65	75	75	74	76
Fergus	80	40	77	86	71	70	77	39	30	54	62
N. Toronto	78	55	83	93	77	85	88	78	85	84	80
Mean	81	64	72	91	77	75	75	67	67	71	74

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - N.S.
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 132. Boron Concentration in the 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					B µg/g						
None											14
Aurora	20	24	24	20	22	19	23	29	27	24	23
Midland	26	43	62	38	42	30	56	108	58	63	52
Sarnia	15	23	30	16	21	20	30	39	28	29	25
Guelph	19	26	25	16	21	19	27	28	17	23	22
Fergus	14	23	13	14	16	14	20	37	20	23	19
N. Toronto	15	21	24	15	18	18	19	26	19	20	19
Mean	18	27	30	20	23	20	29	44	28	30	27

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 133. Boron Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	B µg/g										
None											10
Aurora	15	18	18	15	16	16	16	20	20	18	17
Midland	21	29	47	34	32	19	38	41	38	34	33
Sarnia	12	18	22	14	16	12	15	19	19	16	16
Guelph	15	18	21	13	17	9	15	19	13	14	15
Fergus	12	18	18	12	15	11	12	15	13	13	14
N. Toronto	12	13	20	14	14	10	13	12	11	11	13
Mean	14	19	24	17	18	13	18	21	19	18	18

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	.01	Source x rate	.01
Sludge rate	.01	Source x addition	.01
Sludge addition	.01	Addition x rate	.01
		Source x rate x addition	.01

TABLE 134. Boron Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	B µg/g										
None											17
Aurora	20	26	27	21	23	26	31	38	45	35	29
Midland	29	42	52	54	44	30	57	84	78	62	53
Sarnia	16	25	34	19	23	23	36	54	43	39	31
Guelph	19	29	32	17	24	19	25	35	26	26	25
Fergus	17	27	28	19	22	15	25	30	25	23	23
N. Toronto	17	21	28	16	20	16	21	24	26	21	21
Mean	19	28	33	24	26	21	32	44	40	34	30

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 135. Cadmium Concentration in 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Cd µg/g						
None											1.67
Aurora	0.40	0.40	0.53	1.00	0.58	0.60	0.50	0.40	1.25	0.69	0.63
Midland	0.22	0.30	0.35	0.45	0.33	0.18	0.30	0.30	0.30	0.26	0.30
Sarnia	0.55	1.35	1.80	1.20	1.23	0.80	1.60	1.85	2.20	1.61	1.42
Guelph	1.45	3.00	3.75	3.25	2.86	2.05	4.10	5.20	3.30	3.66	3.26
Fergus	0.30	1.00	0.48	1.70	0.87	0.40	0.95	1.07	0.87	0.83	0.85
N. Toronto	0.48	0.43	0.55	1.00	0.61	1.00	0.60	0.50	0.67	0.69	0.65
Mean	0.57	1.08	1.24	1.43	1.08	0.84	1.34	1.55	1.43	1.29	1.19

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - N.S.

Source x rate x addition - N.S.

TABLE 136. Cadmium Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Cd µg/g										
None											1.45
Aurora	0.67	0.70	0.63	1.40	0.85	0.53	0.55	0.55	0.73	0.59	0.72
Midland	0.43	0.43	0.48	0.69	0.50	0.45	0.47	0.53	0.58	0.51	0.51
Sarnia	1.56	1.82	2.15	2.10	1.91	1.18	2.00	2.39	2.94	2.13	2.02
Guelph	3.62	6.53	6.88	4.98	5.50	2.08	4.05	6.18	2.08	3.59	4.55
Fergus	1.02	1.50	1.37	1.73	1.40	0.86	0.85	0.80	1.03	0.88	1.14
N. Toronto	1.03	1.19	1.00	2.20	1.35	0.89	0.79	0.75	0.93	0.84	1.10
Mean	1.38	2.03	2.08	2.18	1.92	1.00	1.45	1.87	1.38	1.42	1.67

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition -.01
Addition x rate -N.S.
Source x rate x addition - N.S.

TABLE 137. Cadmium Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Cd µg/g										
None											1.05
Aurora	0.65	0.55	0.55	1.45	0.80	0.35	0.55	0.60	1.10	0.65	0.73
Midland	0.38	0.55	0.75	0.55	0.56	0.30	0.45	0.40	0.45	0.40	0.48
Sarnia	1.30	1.54	2.20	2.50	1.88	2.10	1.75	2.50	2.50	2.21	2.05
Guelph	4.05	5.20	8.00	4.40	5.41	2.40	4.25	8.05	3.40	4.53	4.97
Fergus	0.80	1.40	1.90	1.74	1.46	0.95	1.10	0.60	0.58	0.81	1.13
N. Toronto	1.10	0.83	0.95	1.50	1.09	0.85	1.10	0.90	1.05	0.98	1.03
Mean	1.38	1.68	2.39	2.02	1.87	1.16	1.53	2.18	1.51	1.59	1.73

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .05

Source x rate - .01

Source x addition - N.S.

Addition x rate - N.S.

Source x rate x addition - N.S.

TABLE 138. Cadmium Concentration in Crops 1 to 8 of Ryegrass Receiving Sewage Sludges from Guelph and North Toronto before each Crop*.

Crop	Control(NH_4NO_3)	Guelph			North Toronto		
		kg N/ha					
	200	200	800	1600	200	800	1600
		µg Cd/g					
First	0.55	1.03	2.15	2.60	0.70	0.70	0.85
Second	0.35	1.10	2.65	5.61	0.45	0.35	0.40
Third**	0.40	0.65	1.90	2.45	1.45	0.55	0.70
Fourth	0.31	0.86	2.18	3.14	0.38	0.64	0.44
Fifth**	0.60	0.95	2.25	3.70	0.50	0.60	0.65
Sixth	1.65	2.05	4.10	5.20	1.00	0.60	0.50
Seventh**	1.45	2.08	4.05	6.18	0.89	0.79	0.75
Eighth	1.05	2.40	4.25	8.05	0.85	1.10	0.90

*The sludge from Guelph supplied the greatest amount of cadmium in the experiment, while the cadmium content of the North Toronto sludge is near the average of the sludges used.

**Plots were leached after sludge application but before seeding.

TABLE 139. Chromium Concentration in 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Cr µg/g						
None											0.8
Aurora	0.75	0.75	0.70	1.40	0.90	1.50	0.80	0.95	1.45	1.18	1.04
Midland	0.70	0.75	0.70	0.95	0.77	0.75	0.65	0.60	0.65	0.66	0.72
Sarnia	0.75	0.80	0.75	0.75	0.76	0.85	0.80	0.70	0.80	0.79	0.77
Guelph	0.60	0.70	0.80	0.65	0.69	0.65	0.75	0.91	1.10	0.85	0.77
Fergus	0.65	0.85	1.12	0.85	0.87	1.00	0.85	1.42	0.62	0.97	0.92
N. Toronto	0.70	0.85	0.80	0.70	0.76	0.80	0.90	0.80	1.00	0.86	0.82
Mean	0.69	0.78	0.81	1.57	0.96	0.93	0.79	0.89	0.93	0.87	0.93

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.50 and 0.01 probability

Sludge source - .01

Sludge rate - N.S.

Sludge addition - .05

Source x rate - N.S.

Source x addition - N.S.

Addition x rate - N.S.

Source x rate x addition - N.S.

TABLE 140. Chromium Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Cr µg/g										
None											0.71
Aurora	0.67	0.71	0.68	0.60	0.66	0.56	0.72	0.53	0.74	0.64	0.65
Midland	0.59	0.76	0.61	0.63	0.65	0.75	0.59	0.67	0.63	0.66	0.65
Sarnia	0.77	0.67	0.59	0.59	0.66	0.85	0.91	0.87	0.73	0.84	0.75
Guelph	0.61	0.91	0.52	0.72	0.69	0.75	0.67	0.79	0.67	0.72	0.70
Fergus	0.56	0.85	0.89	0.99	0.82	0.61	1.30	0.80	0.92	0.91	0.86
N. Toronto	0.63	0.50	0.62	0.47	0.56	1.04	0.76	0.92	0.71	0.86	0.71
Mean	0.64	0.73	0.65	0.67	0.67	0.76	0.82	0.76	0.73	0.77	0.72

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .05

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - N.S.

Source x rate x addition - .01

TABLE 141. Copper Concentration in 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Cu µg/g						
None											22
Aurora	15	20	26	21	20	16	20	23	23	20	20
Midland	16	23	25	21	21	12	24	25	18	20	20
Sarnia	11	27	28	24	22	14	26	33	29	25	24
Guelph	15	27	31	28	25	18	27	33	27	26	26
Fergus	14	27	31	30	25	23	32	37	31	31	28
N. Toronto	13	19	21	18	17	21	25	24	25	24	21
Mean	14	23	27	23	22	17	25	29	25	24	23

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - N.S.

Source x rate x addition - N.S.

TABLE 142. Copper Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Cu µg/g										
None											13
Aurora	6	15	21	16	14	12	15	20	15	15	15
Midland	10	19	25	18	18	12	21	22	23	19	19
Sarnia	5	14	31	21	18	10	14	34	31	22	20
Guelph	8	11	28	31	19	18	25	34	26	26	22
Fergus	9	18	36	24	22	24	34	40	32	32	27
N. Toronto	8	15	14	19	14	12	19	19	20	17	16
Mean	8	15	26	21	17	14	21	28	24	22	20

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	- .01
Sludge addition	- .01	Addition x rate	- .01
		Source x rate x addition	- .01

TABLE 143. Copper Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Cu µg/g										
None											10
Aurora	10	10	14	11	11	16	22	23	22	21	16
Midland	15	18	20	14	17	19	25	29	23	24	20
Sarnia	15	14	23	20	18	18	27	34	28	27	22
Guelph	17	16	21	22	19	21	29	32	27	27	23
Fergus	18	18	34	28	24	26	39	43	41	37	30
N. Toronto	17	13	12	19	15	21	27	26	24	24	20
Mean	15	15	20	19	17	20	28	31	27	27	22

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .05

TABLE 144. Copper Concentration in Crops 1 to 8 of Ryegrass Receiving Sewage Sludges from Sarnia and North Toronto before each Crop.

Crop	Control (Ammonium Nitrate)	Sarnia			North Toronto		
				kg N/ha			
	200	200	800	1600	200	800	1600
				µg Cu/g			
First	11	15	19	20	13	17	17
Second	17	25	32	31	26	28	27
Third*	10	6	10	11	8	12	13
Fourth	14	12	18	25	11	17	19
Fifth*	14	14	17	20	10	16	18
Sixth	22	14	26	33	21	25	24
Seventh*	13	10	14	34	12	19	19
Eighth	10	18	27	35	21	27	26

* Plots were leached after sludge application but before seeding.

TABLE 145. Nickel Concentration in 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Ni µg/g										
None											1.2
Aurora	1.9	1.0	1.5	7.0	2.8	1.0	1.1	1.9	1.4	1.3	2.1
Midland	7.5	23.9	33.5	30.0	23.8	12.0	34.5	35.5	37.9	29.9	26.8
Sarnia	0.4	0.6	0.5	0.9	0.6	0.7	1.2	2.1	1.5	1.4	0.9
Guelph	0.9	1.3	1.8	1.8	1.5	1.3	3.1	3.6	5.6	3.4	2.4
Fergus	2.1	5.9	8.4	3.1	4.9	1.9	6.6	11.5	8.9	7.2	6.0
N. Toronto	1.0	1.1	1.2	1.5	1.2	0.8	2.3	2.4	3.1	2.1	1.6
Mean	2.3	5.6	7.8	7.4	5.8	3.0	8.1	9.5	9.7	7.6	6.7

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 146. Nickel Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

Sludge	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Ni µg/g										
None											1.3
Aurora	0.4	0.8	1.5	1.4	1.0	0.6	0.6	1.0	0.5	0.6	0.8
Midland	8.6	27.5	39.5	41.5	29.3	11.5	32.5	40.0	39.0	30.9	30.0
Sarnia	1.0	0.7	0.9	1.0	0.9	0.6	0.9	1.8	1.5	1.2	1.0
Guelph	1.0	1.4	1.6	3.1	1.8	0.6	1.5	2.1	1.2	1.3	1.6
Fergus	0.8	4.4	11.1	3.9	5.0	1.5	4.3	8.7	7.8	5.6	5.3
N. Toronto	0.8	1.1	0.8	2.3	1.2	0.5	0.8	1.2	1.9	1.1	1.2
Mean	2.1	6.0	9.2	8.8	6.5	2.5	6.8	9.1	8.6	6.8	6.6

*Sludge was added before the first crop but not before crops 2, 3, 4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - N.S.

Source x rate - .01
Source x addition - N.S.
Addition x rate - N.S.
Source x rate x addition - N.S.

TABLE 147. Nickel Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Ni µg/g										
None											0.9
Aurora	1.1	1.3	1.4	1.4	1.3	1.1	1.2	1.2	1.1	1.2	1.2
Midland	7.7	19.5	30.0	42.4	24.9	12.9	28.0	42.0	36.8	30.0	27.4
Sarnia	1.1	1.0	1.4	1.4	1.2	1.2	1.4	2.2	1.5	1.6	1.4
Guelph	1.4	1.5	1.7	2.6	1.8	1.3	1.8	2.5	1.7	1.8	1.8
Fergus	1.4	3.5	8.2	3.9	4.3	1.9	10.5	4.0	8.3	6.2	5.2
N. Toronto	1.4	1.1	1.7	2.1	1.6	1.5	1.5	1.6	1.3	1.5	1.5
Mean	2.4	4.7	7.4	8.9	5.8	3.3	7.4	8.9	8.5	7.0	6.4

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 148. Nickel Concentration in Crops 1 to 8 of Ryegrass Receiving Sewage Sludges from Midland and North Toronto before Each Crop.

Crop	Control (NH_4NO_3)	Midland			North Toronto		
		kg N/ha					
	200	200	800	1600	200	800	1600
		µg Ni/g					
First	2.0	8.5	32.0	32.0	3.5	4.0	4.5
Second	1.8	14.6	36.3	40.8	1.0	1.1	1.9
Third*	0.5	14.5	22.5	34.5	1.0	0.5	2.0
Fourth	2.0	18.8	36.8	51.3	3.9	3.4	4.4
Fifth*	3.0	8.1	23.0	29.0	1.0	1.5	3.5
Sixth	1.2	12.0	35.0	36.0	0.8	2.2	2.4
Seventh*	1.3	11.5	32.5	40.0	0.5	0.8	1.2
Eight	0.9	12.9	28.0	42.0	1.5	1.5	1.6

The sludge from Midland supplied the greatest amount of nickel in the experiment, while the North Toronto sludge may be considered to be average among the sludges used in its nickel content.

*Indicates pots were leached after sludge application but before seeding

TABLE 149. Lead Concentration in 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Pb µg/g						
None											0.55
Aurora	0.60	0.85	0.65	0.40	0.63	0.45	0.75	1.00	0.85	0.76	0.69
Midland	0.60	0.75	0.80	1.20	0.83	0.60	1.00	0.85	0.50	0.74	0.79
Sarnia	0.55	0.75	1.40	0.90	0.90	0.85	0.95	0.90	0.95	0.91	0.91
Guelph	0.75	0.80	1.00	0.65	0.80	0.85	0.80	0.95	0.85	0.86	0.83
Fergus	1.45	1.25	0.82	0.70	1.05	0.80	0.85	1.62	1.12	1.09	1.08
N. Toronto	0.55	0.80	1.05	0.60	0.75	0.90	0.60	0.70	0.90	0.78	0.76
Mean	0.75	0.87	0.95	0.74	0.83	0.74	0.83	1.00	0.86	0.86	0.84

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .05

Sludge addition - N.S.

Source x rate - N.S.

Source x addition - N.S.

Source x rate x addition - .01

Addition x rate - N.S.

TABLE 150. Lead Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	Mean
	Pb µg/g										
None											0.30
Aurora	0.49	0.45	0.65	0.75	0.58	0.80	0.80	0.85	0.80	0.81	0.70
Midland	0.80	0.60	0.65	1.55	0.90	0.95	1.05	1.15	0.70	0.96	0.93
Sarnia	1.05	1.30	1.65	1.20	1.30	1.25	1.35	1.35	0.95	1.23	1.26
Guelph	0.39	0.95	1.10	0.65	0.77	1.30	1.80	1.40	1.60	1.53	1.15
Fergus	0.79	1.05	0.80	0.60	0.81	0.45	0.60	0.80	1.20	0.76	0.79
N. Toronto	0.99	0.90	0.70	0.65	0.81	1.50	0.80	0.70	0.70	0.93	0.87
Mean	0.75	0.88	0.93	0.90	0.86	1.04	1.07	1.04	0.99	1.04	0.95

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Signifiance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - N.S.

Sludge addition - .01

Source x rate - N.S.

Source x addition - .01

Addition x rate - N.S.

Source x rate x addition - .05

TABLE 151. Zinc Concentration in 6th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Before 6th Crop					Sludge Added Before 6th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					Zn μg/g						
None											51
Aurora	28	39	57	43	42	35	44	70	57	51	64
Midland	28	52	73	44	49	32	69	78	49	57	53
Sarnia	72	189	303	232	199	104	292	490	550	359	278
Guelph	60	106	139	122	106	69	120	170	185	136	121
Fergus	68	245	228	215	189	105	252	349	294	250	219
N. Toronto	40	78	86	68	68	61	117	130	140	112	90
Mean	49	118	148	120	109	68	149	214	212	160	135

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - N.S.
Source x rate x addition - .01

TABLE 152. Zinc Concentration in 7th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Zn $\mu g/g$										
None											36
Aurora	23	39	59	40	40	27	38	60	36	40	40
Midland	22	48	74	43	47	35	62	85	70	63	55
Sarnia	57	169	343	249	204	99	209	426	413	286	245
Guelph	50	84	134	130	99	50	84	120	64	79	89
Fergus	56	198	357	213	206	92	181	246	240	189	198
N. Toronto	32	73	72	80	64	47	75	86	90	75	69
Mean	40	102	173	126	110	58	108	170	152	122	116

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 153. Zinc Concentration in 8th Crop of Ryegrass after Addition of Sewage Sludge before each of the First Five Crops.

	Sludge Not Added Since 5th Crop					Sludge Added Before 8th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	Zn µg/g										
None											33
Aurora	36	30	50	42	39	27	48	63	48	46	43
Midland	31	51	68	42	48	37	64	94	65	65	56
Sarnia	118	187	318	256	219	178	309	530	336	338	279
Guelph	81	112	149	124	116	60	110	157	102	107	112
Fergus	85	238	408	300	258	143	388	320	388	310	284
N. Toronto	57	49	78	72	64	60	121	129	113	106	85
Mean	68	111	178	139	124	84	173	215	175	162	143

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 154. Zinc Concentration in Crops 1 to 8 of Ryegrass Receiving Sewage Sludges from Sarnia and North Toronto before Each Crop.

Crop	Control (NH_4NO_3)	Sarnia			North Toronto		
			kg N/ha				
	200	200	800	1600	200	800	1600
			µg Zn/g				
First	43	59	167	241	53	64	72
Second	38	105	218	211	37	66	81
Third*	31	92	146	245	41	70	102
Fourth	32	64	156	103	29	68	112
Fifth*	33	44	122	165	30	58	92
Sixth	51	104	292	490	61	117	130
Seventh*	36	99	209	426	47	75	86
Eighth	33	177	309	530	60	121	130

The sludge from Sarnia supplied the greatest amount of zinc in the experiment, while the North Toronto sludge may be considered to be average among the sludges used in its zinc content

*Indicates pots were leached after sludge application but before seeding.

TABLE 155. Mercury Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.

Sludge Treatment	Sludge Not Added After 5th Crop	Sludge Added Before Each Crop
	µg Hg/g	
6th Crop		
Midland 800 kg N/ha	0.07	0.07
Midland 1600 kg N/ha	0.07	0.08
N. Toronto 800 kg N/ha	0.09	0.08
N. Toronto 1600 kg N/ha	0.08	0.08
Control	------------- 0.07 -----------------	
7th Crop		
Midland 800 kg N/ha	0.07	0.07
Midland 1600 kg N/ha	0.08	0.08
N. Toronto 800 kg N/ha	0.08	0.08
N. Toronto 1600 kg N/ha	0.09	0.08
Control	------------- 0.07 ----------------	
8th Crop		
Midland 800 kg N/ha	0.09^{+}	0.05^{+}
Midland 1600 kg N/ha	0.10^{+}	0.10^{+}
N. Toronto 800 kg N/ha	0.09^{+}	0.07
N. Toronto 1600 kg N/ha	0.09^{+}	0.08
Control	------------- 0.06^{+} ---------------	

+ Indicates result of one replicate or of samples composited from two replicates because of insufficient plant material.

TABLE 156. Molybdenum Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.

Sludge Treatment	Sludge Not Added After 5th Crop.	Sludge Added Before Each Crop
	µg Mo/g	
6th Crop		
Midland, 800 kg N/ha	0.63	1.02
Midland, 1600 kg N/ha	0.90	0.98
Guelph, 800 kg N/ha	1.80	0.70
Guelph, 1600 kg N/ha	1.02	1.16
Control	0.30	
7th Crop		
Midland, 800 kg N/ha	0.54	0.50
Midland,1600 kg N/ha	0.59	0.48
Guelph, 800 kg N/ha	1.05	1.06
Guelph,1600 kg N/ha	0.89	0.87
Control	0.27	
8th Crop		
Midland 800 kg N/ha	0.28+	1.90+
Midland,1600 kg N/ha	1.61	1.71
Guelph,800 kg N/ha	0.65	1.59
Guelph,1600 kg N/ha	0.89	1.85
Control	0.33	

+ Indicates result of one replicate or of samples composited from two replicates because of insufficient plant material.

TABLE 157. Selenium Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.

Sludge Treatment	Sludge not Added After 5th Crop	Sludge Added Before Each Crop
	μg Se/g	
6th Crop		
Aurora 1600 kg N/ha	0.04	0.07[+]
Midland 1600 kg N/ha	-	0.03
Midland 1600 kg N/ha*	-	0.03
Guelph, 800 kg N/ha	-	0.04
Guelph 1600 kg N/ha	0.14	0.07
Control	0.02[+]	
7th Crop		
Aurora 1600 kg N/ha	0.06[+]	0.04
Midland 1600 kg N/ha	0.04[+]	0.04[+]
Midland 1600 kg N/ha*	-	0.03
Guelph 1600 kg N/ha	0.06	0.12
Control	0.02[+]	
8th Crop		
Aurora 1600 kg N/ha	0.06[+]	0.06[+]
Aurora 1600 kg N/ha*	0.05[+]	0.06
Midland 1600 kg N/ha	0.06[+]	-
Midland 1600 kg N/ha*	0.05[+]	0.04
Guelph 1600 kg N/ha	0.12[+]	0.04
Guelph 1600 kg N/ha*	—	0.11
Control	0.07[+]	

*Sludge added before first crops but not before crops 2, 3, 4 and 5.

+Indicates result of one of two replicates, or of samples composited from two replicates if plant material was insufficient.

Some treatments were analysed in one crop but not in another because of lack for material for analysis.

6 EXTRACTION OF METALS IN SOIL

The measurement of total metal content of soils requires very laborious dissolution techniques using either digestion with HF or fusion with Na_2CO_3. Aqua regia has been used to extract metals from sewage sludge with better than 90% recoveries for most metals (Van Loon, 1974). Elsewhere in the report, we determined the movement of sludge-added metals in the soil using aqua regia as an extractant. The following are the results of preliminary investigations to determine if aqua regia could satisfactorily extract and recover metals added in sludge to soil.

6.1 Materials and Methods

The location and most recent usage of the 21 samples of nine different soils used are described in Table 158.

Air-dried samples were ground to pass through a 2 mm stainless steel sieve. Subsamples were taken and ground with a mullite pestle and mortar to pass through a 100-mesh sieve.

Total metal content was determined using HF-HCl digestion (Pawluk, 1967), with the following modifications to include trace metal analysis: ignition at 400°C to destroy the organic matter, and dissolving the digestion residue in 8 ml of 2 N HCl and diluting to 25 ml (instead of 250 ml).

Extraction with aqua regia followed the method of Van Loon and Lichwa (1973), but using one gram of soil.

Elemental analysis was made with a Techtron AA6 atomic absorption spectrophotometer, using a simultaneous background correction when required. Results are based on at least duplicated runs.

6.2 Results and Discussion

In this section, recovery of metals from soil with aqua regia is presented and discussed with respect to total metal extraction with HF-HCl. Precision of analysis was not always completely satisfactory because of the extreme difficulty in obtaining a representative subsample from some samples. It was therefore necessary in some instances to report the mean of triciplicate or quadruplicate analyses results and these are presented in Table 159.

Aluminum recovery was poor, mostly 50% or less. This is not unexpected as aqua regia only partially breaks down the silicate minerals.

Calcium recovery was variable from soil to soil, ranging from less than 20% to 100%, but was mainly less than 75%. Recovery appeared to be lower in cultivated soil to which no sludge was added.

Iron recovery varied from 49-90%, with the recovery from sludge-amended soil approximately 75%.

Manganese extractability with aqua regia ranged from 60 to 100%. Complete recovery was obtained with sludge-amended Grimsby sandy loam but not with the unamended soil. Recovery of Mn with aqua regia from sludge-amended soils from the field experiments was lower than from the greenhouse experiment.

Cadmium recovery was consistently greater with aqua regia than recovery with HF-HCl. This suggests that Cd may be lost in the HF-HCl method.

Copper extraction efficiency with aqua regia was mostly within ± 20% of that with HF-HCl, indicating the recovery was essentially complete, particularly with sludge-amended soils.

Chromium recovery varied from 38% to 120%, with that of sludge-amended soils ranging from 75 to 120%, thus indicating more or less complete recovery of chromium added in sludge. The lower recovery of 'native' soil chromium in samples one to eight and in cultivated soils not receiving sludge suggests that the Cr in these soils might be held in mineral structures.

Lead recovery with aqua regia ranged from 80 to 120% except with the low lead samples from check plots of experiments with sludge. This indicates that Pb added in sludge to soils was more or less completely recovered.

Nickel recovery was in the range of 80 to 110%. An exception was a check plot soil from a field experiment where recovery was 63%. The results suggest that sludge Ni added to soil was nearly completely extracted.

Zinc recovery ranged from 65 to 100%. An exception was sample number nine from which only 47% Zn was extracted with aqua regia. The majority of sludge-amended soil samples gave recoveries exceeding 80%.

6.3 Summary and Conclusions

Aqua regia only partially extracts Al, Fe, Ca and Cr from soil. The amounts of Al and Fe added in sludges are small compared to 'native' soil Al and Fe, making an assessment of extractability of sludge-added Al and Fe difficult. However, aqua regia only partially recovers Ca in lime-sludge amended soil. More or less complete extraction was achieved for Cd, Cu, Pb, Ni and Zn. Aqua regia extracts had higher Cd values than HF-HCl extracts, suggesting that Cd may be lost in some way in the latter dissolution technique despite precautions such as lowering the ignition temperature to 400°C. In both loamy sand (Grimsby and Caledon) soils that were used in sludge experiments, 'native' soil Pb, Zn, Cu and Ni in check treatments appear to be incompletely extracted. This might, however, be due to the intrinsic low levels in the unamended soil making chemical analysis less precise. In conclusion, aqua regia is a satisfactory extractant of Cd, Cu, Pb, Ni, Zn and to a lesser extent Cr, for use in measuring metal accumulations resulting from sludge additions in soils.

TABLE 158. Description of Soil Samples Used.

Sample No.	Description
1	A sandy loam from a peach orchard near Welland, Ontario; unsprayed area
2	As in 1, but from a sprayed area
3	Snow dump site, west of St. Paul Street, St. Catharines, Ontario
4	Surface soil, 200 ft. southwest of Inco Steel Stack
5	Surface soil, 1000 ft. northeast of Inco Steel Stack
6	Surface soil at the end of Gordon Street between Union Carbide plant and canal, Port Colborne, Ontario
7	Snow dump site near North Toronto sewage treatment plant
8	A loam soil that had received 7 years of sludge application, south of control tower, Toronto airport
9	Grimsby sandy loam, check treatment, Greenhouse experiment
10a* 10b	As in 9 but received lime-treated sludge from Midland
11a 11b	As in 9, but received alum-treated sludge from Guelph
12a 12b	As in 9, but received iron-treated sludge from Fergus
13a 13b	As in 9, but received iron-treated sludge from North Toronto
14	Conestoga silt loam, surface soil, cropped to corn; check plot
15	As in 14, but received lime-sludge for 3 years
16	As in 14, but received alum-sludge for 3 years
17	As in 14, but received iron-sludge for 3 years
18	Caledon loamy sand, surface soil; cropped to corn, check plot.
19	As in 18 but received alum-sludge over a 3 year period
20	As in 18 but received lime sludge over a 3 year period
21	As in 18 but received iron sludge over a 3 year period

*a sludge applied at 1600 kg N/ha once only to crop 1.

b sludge applied at 1600 kg N/ha/crop for five crops.

TABLE 159. Extraction of Metals from Various Soil Samples with Hydrofluoric Acid and Aqua Regia.

Sample No.	Al		Ca		Fe		Mn		Cd	
	AR	HF-HCl	AR	HF-HCl	AR	HF-HCl	AR	HF-HCl	AR	HF-HCl
	←-----------mg/g-----------→								µg/g	
1	9	35	1.5	5.1	10	16	0.33	0.29	0.30	0.20
2	11	32	2.1	5.2	11	14	0.15	0.22	0.30	0.20
3	14	28	41	56	33	43	0.76	1.07	0.57	0.50
4	4	27	20	33	204	227	1.30	2.30	3.5	4.1
5	30	56	30	27	34	43	0.54	0.78	0.47	0.20
6	24	57	17	17	17	22	3.80	4.25	1.15	1.04
7	13	28	54	104	17	28	0.41	0.86	2.2	2.0
8	30	61	4.0	8.0	26	33	0.69	0.73	0.87	0.40
9	12	58	0.6	5.5	17	28	0.89	1.35	0.30	0.30
10a	13	43	29	40	17	22	0.81	0.91	1.8	1.4
10b	14	45	3.5	7.4	18	23	0.90	0.97	0.90	1.0
11a	14	50	2.5	7.0	19	25	0.85	0.88	13.2	12.0
11b	13	41	0.8	5.0	18	21	0.85	0.75	2.9	2.3
12a	13	46	1.5	5.7	19	23	0.86	0.60	1.5	0.80
12b	14	44	0.8	5.1	19	22	0.90	0.84	0.90	0.60
13a	13	41	1.3	5.3	19	24	0.73	0.74	1.0	0.50
13b	12	40	0.7	5.1	18	24	0.82	0.83	0.40	0.30
14	15	47	8.0	15	20	28	0.75	0.89	0.38	0.20
15	14	43	26	37	19	26	0.75	0.90	0.53	0.35
16	17	49	11	16	19	27	0.69	0.81	0.66	0.47
17	17	43	9.0	12	23	29	0.74	0.81	1.27	0.98
18	9	39	4.0	10	11	17	0.64	0.87	0.30	0.20
19	9	39	5.0	9.0	11	16	0.53	0.65	0.70	0.45
20	9	33	24	34	12	17	0.62	0.78	0.76	0.58
21	9	38	8.0	10	12	18	0.59	0.78	0.68	0.58

TABLE 159. (Cont'd)

Sample No.	Cr		Cu		Pb		Ni		Zn	
	AR	HF-HCl	AR	HF-HCl	AR	HF-HCl	AR	HF-HCl	AR	HF-HCl
	--------------------μg/g--------------------									
1	9	14	24	30	18	24	9	12	45	52
2	9	14	35	42	22	26	10	11	39	53
3	22	47	40	53	123	126	29	39	120	182
4	39	84	1660	1980	309	273	16,500	19,440	1510	1760
5	27	55	236	282	46	57	1,880	2,140	150	213
6	158	569	112	128	62	71	89	98	438	500
7	17	37	51	68	421	436	20	21	249	329
8	26	44	29	31	29	35	20	23	94	119
9	9	27	24	34	15	24	13	16	40	84
10a	149	190	105	104	175	149	717	654	298	304
10b	75	89	46	54	94	92	279	271	103	131
11a	118	154	150	148	77	69	19	19	373	375
11b	44	48	60	60	34	34	12	14	130	155
12a	64	57	237	188	34	28	21	21	632	615
12b	32	41	99	98	18	21	14	13	175	203
13a	19	26	59	60	55	45	12	14	134	149
13b	11	23	33	33	22	24	10	13	58	90
14	23	29	19	20	20	21	13	15	84	113
15	25	33	34	33	27	28	13	14	142	150
16	254	208	43	40	29	32	25	25	224	225
17	36	43	66	64	81	78	15	16	185	198
18	13	20	15	18	13	24	6.3	10	73	100
19	133	103	35	18	21	26	14	16	176	169
20	25	28	44	48	24	31	10	11	174	184
21	25	33	34	39	20	24	9	11	121	144

7 NITROGEN STUDIES ON SLUDGE

7.1 General Objectives

1) To determine the availability of N in chemically treated sludges to crop plants.
2) To estimate losses of N to ground and drainage waters.

7.2 Nitrate and Ammonium in Soil Profiles

7.2.1 Objective

To determine the production and movement of NO_3^- in soil of selected sludge-treated plots with respect to soil texture and crop (corn vs grass).

7.2.2 Methods

7.2.2.1 Soil profile sampling for NO_3^-, NH_4^+ and pH. Soil pH, % H_2O, exchangeable NH_4^+, and NO_3^- were determined on samples obtained from the soil profile of selected plots from corn and grass experiments at the Elora Research Station as well as from the corn experiment at Cambridge. These samples were taken in late April to furnish an estimate of NO_3^- losses and changes in pH and exchangeable NH_4^+ over the winter months of 1975-76. Plots receiving 0, 400 and 800 kg N/ha of the iron-sludge were sampled at the 0-6 (0-15), 6-12 (15-30), 12-18 (30-45), 18-24 (45-60), 24-36 (60-90) inch (cm) layers.

7.2.2.2. Subsoil solution sampling. Subsoil solution samplers were placed at the 45 or 90 cm depth in selected plots which received 200, 400, 800, and 1600 kg N/ha as Fe-sludge, 1600 kg N/ha as Al- or Ca- sludge, and 100 and 400 kg N/ha as NH_4NO_3 fertilizer on the corn experiment at the Elora Research Station. Three replicates of most treatments were sampled on April 1 and April 7, 1976, although in some cases samples were only obtainable in one or two of the replicates of each treatment.

Samplers were also placed at the 90 cm depth in plots of the runoff experiment at the Elora Research Station which received 100 kg N/ha as NH_4NO_3 or 800 kg N/ha as Fe-sludge applied in the spring of previous years. Two samplers per plot were placed in each replication of treatments on the 2% slope. Samples were taken on April 1 and April 7, 1977.

Both NO_3^- and Cl^- analyses were made on the collected samples.

7.2.3 Results

7.2.3.1 Soil profile sampling for NO_3^-, NH_4^+ and pH. The NO_3^--N concentration in both the loamy sand (Table 160, Cambridge) and silt loam (Table 161, Elora) profiles of the corn experiments increased significantly where sludge was applied the previous year. In the loam sand profile the NO_3^--N concentration did not appear to increase from the 400 to 800 kg N/ha treatment (Table 160) whereas there was a substantial increase in the silt loam soil profile for these treatments (Table 161). It is noteworthy that the NO_3^--N concentration did not generally vary with depth in the soil profile.

In the grass experiment, the NO_3^--N concentration increased significantly with increasing rate of application of sludge (Table 162). Also, there was a significant decrease in NO_3^--N concentration with depth in the soil profile. The NO_3^--N concentration was generally lower in the soil profile under grass (Table 162) than under corn (Table 161).

The rate of sludge application had no influence on the NH_4^+-N concentration in the soil profile at any of the sites (Tables 160, 161 and 162). There were significant decreases in NH_4-N concentration with depth regardless of sludge treatment.

The pH of the soil profiles generally increased significantly with depth (Tables 160, 161 and 162). The pH decreased with increasing sludge applied in the upper layers of the silt loam profile under corn (Table 161). In the loamy sand profile, the intermediate level of applied sludge (400 kg N/ha) appeared to have caused the greatest reduction in soil pH (Table 160).

7.2.3.2 Subsoil solution sampling. At the 45 cm depth in the corn experiment, the NO_3^--N concentration was much higher with the sludge applications (1600 kg N/ha) than with the NH_4NO_3 (100 kg N/ha)(Table 163). However, even the NO_3^--N concentration with NH_4NO_3 was higher than that normally considered to be acceptable. The Cl^- concentration was also higher with sludge than with NH_4NO_3 fertilizer.

At the 90 cm depth in the corn experiment, the NO_3^--N concentration in the subsoil solution increased threefold with 400 kg N/ha compared with 100 kg N/ha as NH_4NO_3. The NO_3^--N concentration generally increased with the increase in sludge applied although there was some variability from April 1 to April 7. The Cl^- concentration was generally higher with the sludge applications.

In the runoff experiment, the NO_3^--N and Cl^- concentrations were generally higher with the sludge treatment.

7.2.4 Summary and conclusions

The NO_3^--N concentration was higher where sludge was applied in previous years on the corn experiment, suggesting that residual sludge N was being mineralized and nitrified. The NO_3^--N concentration in the soil profile was generally lower under grass than under corn. Subsurface soil solutions sampled in early April contained relatively large quantities of NO_3^--N where excessive quantities of N were applied. Presumably this NO_3^- is liable to leaching into the groundwater or drainage waters.

7.3 Residual Nitrogen Available to Corn

7.3.1 Objective

To estimate the residual N available to a corn crop from sludge applied in previous year(s).

7.3.2 Methods

Different N fertilizer treatments (0, 67, 134 kg N/ha) as NH_4NO_3 were superimposed on plots which were previously used to study sludge nutrient runoff from land with a two percent slope. The N fertilizer treatments were applied just before corn was planted in May. The sludge treatments for each year of the previous three years were as follows.

1) Check - 100 kg N/ha as NH_4NO_3 fertilizer,
2) 200 kg N/ha; sludge applied in winter,
3) 800 kg N/ha; sludge applied in winter,
4) 200 kg N/ha; sludge applied in spring,
5) 800 kg N/ha; sludge applied in spring,
6) 200 kg N/ha; sludge applied in fall,
7) 800 kg N/ha; sludge applied in fall.

The first sludge application was made in the fall of 1972, whereas the last sludge application was made in the winter of 1976 to the appropriate plots. This meant that the plots with the fall and winter sludge treatments received a total of four annual applications of sludge, whereas the plots with the spring sludge treatment received only three annual applications.

The soil in the 0-7 (0-18) and 7-14 (18-36) inch (cm) layers in each of the N fertilizer subplots was sampled on April 8 and June 22. Soil pH, % H_2O, exchangeable NH_3^+ and soluble NO_3^- were determined.

Grain yields were obtained following harvesting on October 14 and expressed on the basis of 15% moisture content.

7.3.3 Results

7.3.3.1 NO_3^--N concentration in soil. The winter and fall applications of sludge appeared to significantly increase the NO_3^--N concentration over the check treatment and spring application treatments in both soil layers at the April 8 sampling (Table 164). The lower concentration in plots where sludge was applied last in the spring, 1975, was probably due to the fact that the applications in the fall, 1975, and winter, 1976, contributed significantly to the ammonium supply and hence the nitrate content in the soil, whereas the ammonium in the previous spring application had disappeared over the more lengthy time interval. However, it is surprising that some nitrification of ammonium occurred as early as April 8.

By the June 22 sampling time, sludge applied the previous fall or winter greatly increased the NO_3^--N concentration in both layers over that for the check plot (Table 164). With the spring application, only the 800 kg N/ha treatment of sludge substantially increased the NO_3^--N concentration in the 0-7 inch layer.

The application of fertilizer N before planting in 1976 resulted in significant increases of NO_3^--N concentration with the June 22 sampling (Table 165).

7.3.3.2 NH_4^+-N concentration in soil. The NH_4^+-N concentration increased with sludge rate in both soil layers over those in the check plot, with the exception of the spring applied sludge treatment at the of the April 8 sampling (Table 166). Increasing the quantity of NH_4NO_3 applied before planting in 1976 generally increased the NH_4^+-N concentration in both soil layers with the June 22 sampling (Table 167).

7.3.3.3 Soil pH. Although pH changes were not great, increasing the rate of NH_4NO_3 applied before planting in 1976 resulted in a significant decrease in pH by the time of the June 22 sampling (Table 168). This was probably due to acidification caused by nitrification of NH_4^+ ions from the NH_4NO_3 fertilizer. Previous applications of sludge, particularly at the 800 kg N/ha level, tended to decrease soil pH slightly (Table 168).

Soil pH of the 7-14 inch layer (7.58) was generally higher that that for the 0-7 inch layer (7.49) at the April 8 sampling. At the June 22 sampling, the pH of the 7-14 inch layer was 7.38, whereas that for the 0-7 inch layer was 7.30 showing a slight decrease when compared with the April 8 samples.

7.3.3.4 Grain corn yields. There was an expected response to N fertilizer applied to the check plots (Table 169). There was an apparent response to fertilizer N where 200 kg N/ha as sludge was applied, but not where 800 kg N/ha was applied in the previous fall or winter. Where sludge was previously applied in the spring at the 200 kg N/ha rate, there was no apparent residual effect and this was comparable with the check plot response to N applied in 1976. However, there was an apparent residual affect with spring applied sludge at the 800 kg N/ha rate, although there was apparently insufficient N with this treatment to fully supply the crop requirement for 1976.

7.3.4 Summary and conclusions

Applications of sludge the previous fall or winter significantly increased NO_3^--N content in the 0-7 and 7-14 inch soil layers. However, the NO_3^--N content was not as great where sludge was applied in previous springs. There was some nitrification of residual sludge N by June 22 where 800 kg N/ha was applied. The NH_4^+-N concentration in the soil was increased at the April 8 sampling by sludge applications the previous fall and winter, but not the previous spring. The addition of N either as fertilizer or sludge resulted in slight decreases in soil pH.

There was a response to residual sludge N applied in the previous spring(s) only where a rate of 800 kg N/ha was used.

7.4 Ammonia Volatilization Estimates

7.4.1 Objective

To determine the quantity of ammonia volatilized from newly applied sludge in the field by sludge and soil analyses.

7.4.2 Methods

Two gallons of sludge was applied to small plots (4 feet^2 or 0.37 m^2) at the Elora Research Station. The soil (silt loam) was previously rotovated to a depth of approximately 12 cm and then levelled. The sludge layer and soil beneath it were sampled periodically to determine changes in NH_4^+ and NO_3^- levels and hence estimate NH_3 volatilization losses. After the sludge layer was sampled (removed), ten soil cores (2.5 cm diam.) were taken and separated into 0-2, 2-4 and 4-6 cm layers. The ten core samples from each layer were composited and immediately frozen in plastic bags for subsequent determination of H_2O content, exchangeable NH_4^+ and soluble NO_3^-. The first sampling was made 15-30 minutes after sludge application. Samplings were also made on the second, third, and fourth days (at approximately the same time as for day one), and then every third or fourth day until the third week after application. Three sampling periods were chosen as follows to provide a range of soil and atmospheric environment conditions. The sludge source is indicated for each sampling period.

Period	Sludge Source
(a) June 8 - June 24	Guelph
(b) July 27 - August 12	North Toronto
(c) October 5 - October 19	Guelph

7.4.3 Results

Knowing the soluble plus exchangeable NH_4^+-N content of the sludges, it was possible to calculate the quantity applied on an area of one cm^2. Similarly, it was possible to calculate the NH_4^+-N and NO_3^--N concentrations in the sludge and soil layers on a surface area basis knowing the soil bulk density (1.0 g/cc). When these data were evaluated, there were many discrepancies and unexplainable variations so that it was decided to sum and present the data for NH_4^+-N and NH_4^+-N + NO_3^--N concentrations in the sludge and soil layers (Tables 170, 171 and 172).

There was usually a large discrepancy between the quantity of NH_4^+-N applied and that determined in the sludge and soil layers shortly after sampling (Tables 171 and 172). There is no explanation available for this observation. In general, however, the NH_4^+-N content of the sludge and soil layers decreased with time. Rainfall which occurred would not be expected to leach NH_4^+ ions from the sampling zone. Therefore, the only "sinks" for NH_4^+ would be volatilization, immobilization or nitrification.

It appeared that considerable quantities of NH_4^+ were nitrified to NO_3^- even after a surprisingly short period following application. However, the NO_3^- formed following sludge application was subject to leaching with rainfall. Denitrification of NO_3^- may have also occurred in anaerobic microsites in the soil following rainfall events, but this was difficult to ascertain in this study.

7.4.4 Summary and conclusions

Contrary to expectations, determination of NH_4^+-N and NO_3^--N concentrations in sludge and soil layers periodically following sludge application did not provide information of any value on ammonia volatilization. This method was expected to provide some in information on the influence of differences in atmospheric and soil environments on ammonia volatilization in a relatively inexpensive and rapid manner. Such was not the case, which further emphasizes the fact that N is a complex element in our environment. It also appears that measuring NH_3 volatilization under field conditions may only be realistically done using the "meteorological" method reported in the 1975-76 report (Research Report No. 60).

TABLE 160. NO_3-N and NH_4-N Concentrations in and pH of Loamy Sand Profile (Cambridge, Corn Experiment) of Plots having Received Different Quantities of Fe-Treated Sludge. Sampled April 5, 1976.

Depth		Sludge Rate lb N/ac (kg N/ha)			Significance of Effect*		
Inch	(cm)	0	356(400)	712(800)	Depth	Rate	DXR
			NO_3-N µg/g				
0-6	(0-15)	3.4	4.5	4.4			
6-12	(15-30)	3.7	5.7	5.4			
12-18	(30-45)	2.9	5.0	5.4	N.S.	0.005	N.S.
18-24	(45-60)	3.1	6.2	4.9			
24-36	(60-90)	3.2	6.0	3.5			
			NH_4-N µg/g				
0-6	(0-15)	5.2	5.7	5.8			
6-12	(15-30)	3.3	3.4	2.8			
12-18	(30-45	1.8	1.8	1.5	0.005	N.S.	N.S.
18-24	(45-60)	1.4	1.6	1.2			
24-36	(60-90)	1.2	1.2	1.0			
			pH				
0-6	(0-15)	7.9	7.7	7.9			
6-12	(15-30)	8.0	7.7	8.0			
12-18	(30-45)	8.0	7.8	8.0	0.005	0.05	N.S.
18-24	(45-60)	8.1	8.1	8.0			
24-36	(60-90)	8.2	8.1	8.2			

* 0.05, 0.01 and 0.005 indicate level of significance by 'F' test.

N.S. indicates effect not significant at 0.05 level of probability

TABLE 161. NO$_3$-N and NH$_4$-N Concentration in and pH of Silt Loam Profile (Elora, Corn Experiment) of Plots having Received Different Quantities of Fe-Treated Sludge. Sampled April 6, 1976.

Depth		Sludge Rate lb N/ac (kg N/ha)			Significance of Effect*		
Inch	(cm)	0	356(400)	712(800)	Depth	Rate	DXR
			NO$_3$-N µg/g				
0-6	(0-15)	7.3	8.0	13.3			
6-12	(15-30)	6.0	9.2	16.6			
12-18	(30-45)	5.0	9.4	18.4	N.S.	0.005	N.S.
18-24	(45-60)	4.3	8.0	21.9			
24-36	(60-90)	4.2	9.6	20.3			
			NH$_4$ON µg/g				
0-6	(0-15)	5.9	6.2	6.3			
6-12	(15-30	4.0	4.6	3.7			
12-18	(30-45)	1.5	1.8	1.7	0.005	N.S.	N.S.
18-24	(45-60)	1.1	1.1	1.4			
24-36	(60-90)	0.8	1.1	0.8			
			pH				
0-6	(0-15)	7.8	7.7	7.5			
6-12	(15-30)	7.8	7.8	7.6			
12-18	(30-45)	8.0	7.8	7.7	0.005	0.005	N.S.
18-24	(45-60)	8.0	7.9	7.8			
24-36	(60-90)	8.2	8.0	7.9			

* 0.05, 0.01 and 0.005 indicate level of significance by 'F' test.

N.S. indicates effect not significant at 0.05 level of probability.

TABLE 162. NO_3-N and NH_4-N Concentrations in and pH of Silt Loam Profile (Elora, Bromegrass Experiment) of Plots having Received Different Quantities of Fe-Treated Sludge. Sampled April 7, 1976.

Depth		Sludge Rate lb N/ac (kg N/ha)			Significance of Effect *		
Inch	(cm)	0	356(400)	712(800)	Depth	Rate	DXR
			NO_3-N µg/g				
0-6	(0-15)	5.0	6.3	9.3			
6-12	(15-30)	5.4	5.6	8.6			
12-18	(30-45)	3.8	4.7	7.4	0.005	0.005	N.S.
18-24	(45-60)	3.3	4.6	5.4			
24-36	(60-90)	4.3	4.3	5.8			
			NH_4-N µg/g				
0-6	(0-15)	9.2	8.0	6.9			
6-12	(15-30)	5.4	5.5	4.7			
12-18	(30-45)	1.9	2.0	2.2	0.005	N.S.	N.S.
18-24	(45-60)	1.2	1.7	1.3			
24-36	(60-90)	1.0	1.2	0.7			
			pH				
0-6	(0-15)	7.6	7.7	7.6			
6-12	(15-30)	7.6	7.7	7.7			
12-18	(30-45)	7.7	7.8	7.9	0.005	0.05	N.S.
18-24	(45-60)	7.7	7.9	8.0			
24-36	(60-90)	7.8	8.0	8.2			

* 0.05, 0.01 and 0.005 indicate level of significance by 'F' test.

N.S. indicates effect not significant at 0.05 level of probability.

TABLE 163. Nitrate-N and Chloride Concentrations in Soil Solution Sampled at the 45 and 90 cm Depths from the Corn and Runoff Experiments at the Elora Research Station in 1976.

	NO_3^--N		Chloride	
	1/4/76	7/4/76	1/4/76	7/4/76
	(μg/ml)		(μg/ml)	
1. Corn Experiment, Elora				
A. 45 cm depth				
NH_4NO_3, 100 kg N/ha	21 (3)*	24 (3)	13 (3)*	10 (2)
Ca-sludge, 1600 kg N/ha	137 (3)	148 (2)	39 (3)	34 (2)
Al-sludge, 1600 kg N/ha	75 (2)	107 (3)	19 (3)	15 (3)
Fe-sludge, 1600 kg N/ha	80 (2)	102 (3)	26 (3)	24 (3)
B. 90 cm depth				
NH_4NO_3, 100 kg N/ha	38 (2)	43 (1)	34 (2)	23 (2)
NH_4NO_3, 400 kg N/ha	96 (3)	91 (3)	28 (3)	29 (3)
Fe-sludge, 200 kg N/ha	50 (2)	58 (2)	45 (2)	44 (2)
Fe-sludge, 400 kg N/ha	50 (3)	98 (3)	36 (3)	32 (3)
Fe-sludge, 800 kg N/ha	70 (3)	76 (3)	24 (2)	38 (3)
2. Runoff Experiment (90 cm depth)				
NH_4NO_3, 100 kg N/ha	7 (3)	12 (3)	12 (3)	10 (3)
Fe-sludge, 800 kg N/ha (spring applied)	66 (3)	57 (3)	17 (3)	23 (3)

* Numbers in parentheses indicate the number of replicates on which each datum is averaged.

TABLE 164. NO_3-N Concentration in Soil from Residual Sludge Nitrogen Experiment as Affected by Depth and Previous Sludge Treatments Sampled on April 8 and June 22, 1976.

Previous sludge treatments		Date of Sampling					
		April 8			June 22		
		Depth					
Rate kg N/ha	When applied	0 - 7 in.	7 - 14 in	Mean	0 - 7 in	7 - 14 in	Mean
		μg NO_3-N/g					
Check *		5	4	5	36	28	32
200	Winter	13	7	10	54	39	47
800	Winter	28	14	21	91	60	76
200	Spring	6	5	5	31	23	27
800	Spring	8	5	7	49	30	39
200	Fall	12	9	10	49	40	44
800	Fall	31	16	23	82	48	65
Mean		15	8	12	56	38	47

* 100 kg N/ha as NH_4NO_3 applied in Spring

Sludge treatment, depth and sludge - depth interaction are significantly different at 0.005 probability by 'F' test on April 8 and June 22 samplings.

TABLE 165. NO_3-N Concentration in Soil from Residual Sludge Nitrogen Experiment as Affected by Previous Sludge Treatments and Current Fertilizer-N Rates. Sampled June 22, 1976.

Previous sludge treatments		Fertilizer N Rate (kg N/ha as NH_4NO_3)			
Rate kg N/ha	When applied	0	67	134	Mean
		µg NO_3-N/g			
Check*		17	32	46	32
200	Winter	25	27	88	47
800	Winter	48	70	109	76
200	Spring	16	24	40	27
800	Spring	28	33	57	39
200	Fall	27	46	60	44
800	Fall	50	81	64	65
Mean		30	45	66	47

* NH_4NO_3, 100 kg N/ha applied in Spring

Sludge treatment and fertilizer N rate are significantly different at 0.005 probability by 'F' test.

TABLE 166. NH_4-N Concentration in Soil from Residual Sludge Nitrogen Experiment as Affected by Depth and Previous Sludge Treatments. Sampled April 8, 1976.

Previous sludge treatments		Depth		
Rate kg N/ha	When Applied	0-7 in	7-14 in	Mean
		µg NH_4-N/g		
Check*		4	2	3
200	Winter	7	3	5
800	Winter	25	4	14
200	Spring	4	2	3
800	Spring	5	2	4
200	Fall	6	3	5
800	Fall	13	4	9
Mean		9	3	6

* NH_4NO_3, 100 kg N/ha applied in spring.

Sludge treatments are significantly different at 0.05 probability and depth is significantly different at 0.005 probability by 'F' test.

TABLE 167. NH_4-N Concentration in Soil from Residual Sludge Nitrogen Experiment as Affected by Soil Depth and Current Fertilizer Nitrogen Rates. Sampled June 22, 1976.

Current fertilizer N rate (kg/ha)	Depth		
	0-7 in	7-14 in	Mean
	µg NH_4-N/g		
0	6	3	5
67	7	4	5
134	8	5	7
Mean	7	4	6

Soil depths and fertilizer N rates are significantly different at 0.05 probability by 'F' test.

TABLE 168. Soil pH† from Residual Sludge Nitrogen Experiment as Affected by Previous Sludge Treatments and Current Fertilizer-N Rates. Sampled June 22, 1976.

Previous sludge treatments		Fertilizer N Rate (kg N/ha as NH_4NO_3)			
Rate kg/N/ha	When applied	0	67	134	Mean
Check*		7.43	7.39	7.42	7.41
200	Winter	7.51	7.55	7.37	7.47
800	Winter	7.38	7.08	7.18	7.21
200	Spring	7.45	7.36	7.38	7.40
800	Spring	7.39	7.36	7.28	7.34
200	Fall	7.38	7.27	7.20	7.28
800	Fall	7.38	7.15	7.22	7.25
Mean		7.42	7.31	7.29	7.34

* NH_4NO_3 applied in Spring at 100 kg N/ha.
Effects of sludge treatments and fertilizer -N rates are significantly different at 0.005 probability by 'F' test.

† Averaged over 0-14 in. depth.

TABLE 169. Effect of Previous Sludge Treatments and NH_4NO_3 Fertilizer Rates on Corn Grain Yield on 2% Runoff Plots in 1976.

Previous Sludge Treatment	NH_4NO_3 (kg N/ha)			Mean
	0	67	132	
		(kg/ha, 15% H_2O)		
Check (112 kg N/ha, as NH_4NO_3)	5400	6390	7770	6520
200 kg N/ha, winter sludge	6220	7020	6400	6540
800 kg N/ha, winter sludge	7280	7530	6930	7240
200 kg N/ha, spring sludge	5000	6670	6360	6010
800 kg N/ha, spring sludge	7290	7850	7700	7610
200 kg N/ha, fall sludge	6140	7350	6640	6710
800 kg N/ha, fall sludge	8070	7430	7660	7720
Average, 200 kg N/ha sludge	5790	7010	6470	6420
Average, 800 kg N/ha sludge	7540	7600	7430	7530
Overall sludge average	6665	7305	6950	6975

Level of significant differences by 'F' test	
Sludge treatment	0.005 level
NH_4NO_3 fertilizer rate	0.005 level
Sludge x NH_4NO_3 interaction	0.01 level

TABLE 170. Rainfall, and NH_4^+-N and NH_4^+-N plus NO_3^--N Contents in Sludge and Soil Layers Following Sludge Application on June 8, 1976.

Date	Rainfall in (cm)	NH_4^+-N $\mu g/cm^2$	NH_4^+-N + NO_3^--N $\mu g/cm^2$
June 8		810	1090
9		113	427
10		65	420
11		51	276
12			
13	0.08 (0.20)		
14		118	548
15	0.09 (0.23)		
16	0.04 (0.10)		
17		137	551
18	0.12 (0.30)		
19	0.21 (0.53)		
20			
21		97	491
22			
23			
24	0.49 (1.24)	81	466

896 μg NH_4^+-N/cm^2 applied in sludge

TABLE 171. Rainfall, and NH_4^+-N and NH_4^+-N plus NO_3^--N Contents in Sludge and Soil Layers Following Sludge Application on June 27, 1976.

Date	Rainfall in (cm)	NH_4^+-N µg/cm²	NH_4^+-N + NO_3^--N µg/cm²
July 27		461	860
28	0.83 (2.10)	330	558
29	T (T)*		
30	0.27 (0.69)	328	472
31	0.08 (0.20)		
Aug. 1			
2			
3		181	562
4			
5	0.04 (0.10)		
6		149	577
7	0.18 (0.46)		
8	0.49 (1.24)		
9		84	407
10	T (T)		
11	T (T)		
12	0.24 (0.61)	125	698

1487 µg NH_4^+-N/cm² applied in sludge

* T = trace

TABLE 172. Rainfall, and NH_4^+-N and NH_4^+-N plus NO_3^--N Contents in Sludge and Soil Layers Following Sludge Application on October 5, 1976.

Date	Rainfall in (cm)	NH_4^+-N $\mu g/cm^2$	NH_4^+-N + NO_3^--N $\mu g/cm^2$
October 5		150	199
6	0.97 (2.46)	134	188
7	T (T)*		
8	T (T)	124	167
9	0.15 (0.38)		
10			
11			
12		89	137
13	0.25 (0.63)		
14		73	135
15	0.05 (0.13)		
16			
17			
18			
19	0.43 (1.09)	63	162
	305 μg NH_4^+-N/cm^2 applied in sludge		

* T = trace

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